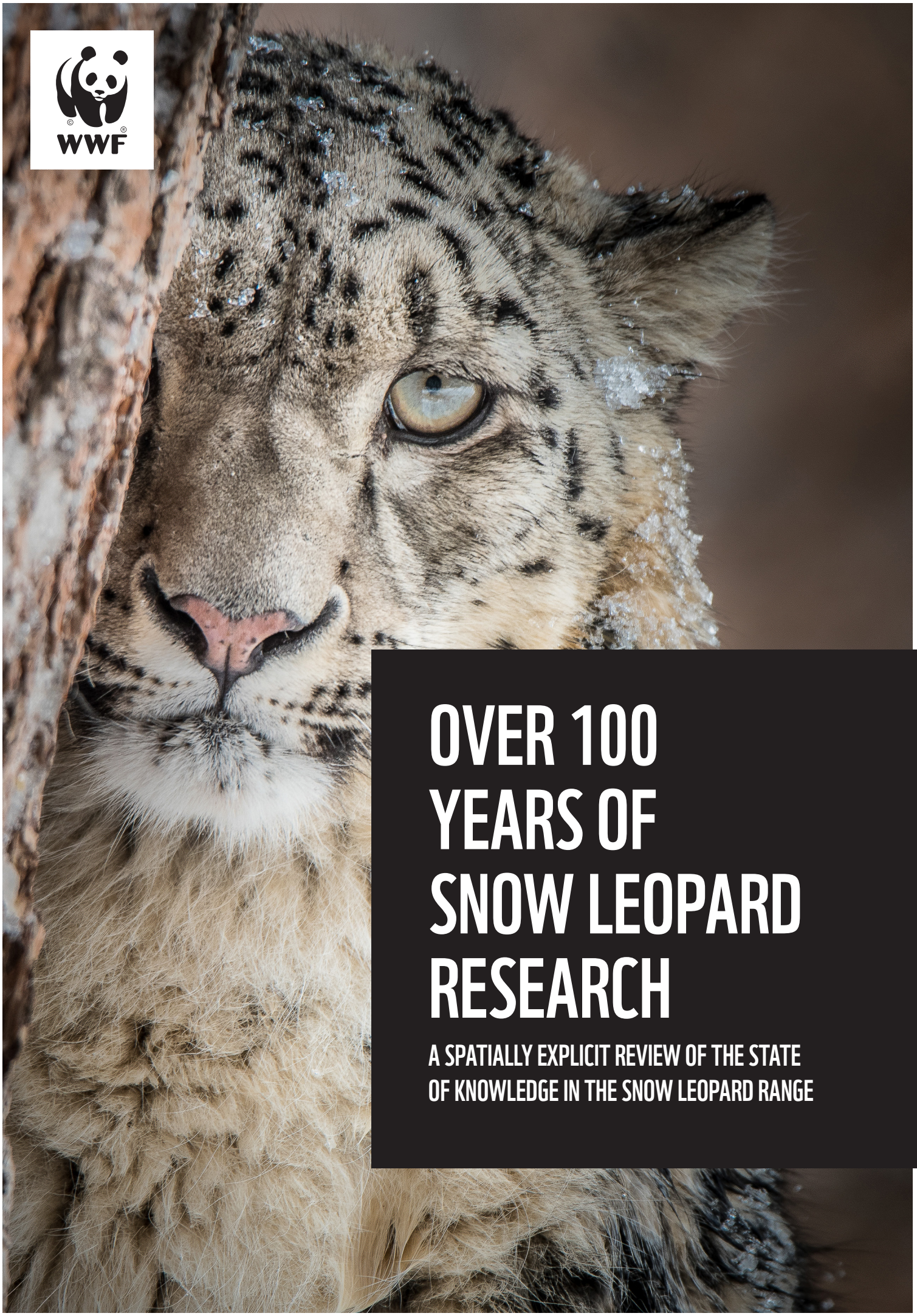

OVER 100 YEARS OF SNOW LEOPARD RESEARCH

A SPATIALLY EXPLICIT REVIEW OF THE STATE OF KNOWLEDGE IN THE SNOW LEOPARD RANGE

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& RASHMI SINGH

CONTENTS

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A snow leopard examining a camera trap in the Upper Spiti Landscape, Western Himalaya

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A Himalayan Ibex, one of the important prey species for snow leopard.

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Typical rugged terrain characterizes snow leopard habitat in the Western Himalaya, India

EXECUTIVE SUMMARY

Evolved to live in some of the world's highest and harshest habitats, the elusive and rare snow leopards (*Panthera uncia*) are undisputed icons of High Asia. Across their distributional range in Central and South Asia, the snow leopard's habitat spans diverse landscapes, with livestock herding being the most dominant form of land use. As a result, areas inhabited by snow leopards and people often overlap, creating challenges as well as opportunities for their conservation.

Snow leopard conservation has received increasing attention in the past two decades and global interest in protecting this unique high-mountain cat continues to rise. However, effective and efficient snow leopard conservation initiatives require multi-dimensional research and collaboration among a diverse array of actors. National governments in snow leopard range, for instance, have repeatedly pledged their support for the conservation of the animal and the breathtaking landscapes they inhabit. These landscapes house an array of unique high-altitude wildlife and provide homes and life-sustaining natural resources to hundreds of millions of people. The mountains of High Asia also form the headwaters of 20 major river basins, an important water source for 22 countries (Sindorf et al., 2014). More than 2 billion people live in these basins which overlap the snow leopard range.

Given the growing interest in and commitment towards conservation of snow leopards and their habitats, it is crucial to examine the depth and breadth of knowledge currently available to inform conservation efforts and identify gaps in that knowledge. We reviewed over 100 years of published research on snow leopards to examine its temporal and spatial trends across an array of thematic areas.

Snow leopard research intensified in the 1970s and studies on snow leopards have continued to increase exponentially since then. However, just four hotspots of snow leopard research (sites with continued multi-year research) have emerged, with less than 23% of the snow leopard range being researched. Nepal, India and Chinahave conducted the most snow leopard research, followed by Mongolia and Pakistan. Our analysis revealed that snow leopard research was highly focussed on ecological research followed by studies on human-wildlife conflict. Most ecological studies focused on estimating the number and distribution of snow leopards and prey species. However, conservationists have surveyed less than 3% of the snow leopard range using rigorous and scientifically acceptable abundance estimation approaches. The lack of attention to the human dimensions of conservation was particularly stark, especially given that the majority of the snow leopard range is inhabited by local communities dependent on livestock herding. More importantly, very few studies evaluated the effectiveness of conservation actions. A lack of evidence demonstrating and quantifying the impacts of conservation interventions is a significant knowledge gap in snow leopard research.

4 hotspots of snow leopard research (sites with continued multi-year research) have emerged, with less than 23% of the snow leopard range being researched.

surveyed less than 3% of the snow leopard range using rigorous and scientifically acceptable abundance estimation approaches.

In this review, we identify and suggest the high-priority research necessary for effective conservation planning for snow leopards and their multiple-use habitat in High Asia.

1. High Asia (> 3000 meters) includes the Altai, Tian Shan, Kunlun, Pamir, Hindu Kush, Karakorum, Tibetan Plateau and Himalayan ranges.

INTRODUCTION

Distinctly adapted to the cold and rugged mountains of Asia, snow leopards (Panthera uncia) are masters of stealth and camouflage. Their legendary ability to blend with their surroundings has earned them the epithet 'ghost of the mountains'. Arguably, the most iconic emblems of High Asia, snow leopards inhabit the mountain ranges of 12 countries across Central and South Asia: China, Bhutan, Nepal, India, Pakistan, Afghanistan, Tajikistan, Uzbekistan, Kyrgyzstan, Kazakhstan, Russia and Mongolia. Fewer than 6,400 snow leopards are thought to survive in a potential habitat range spanning approximately 1.8 million square kilometres (Snow Leopard Working Secretariat, 2013). Snow leopard habitats in the high mountains of Asia host a diversity of high-altitude adapted species and provide life-sustaining natural resources, such as freshwater, for hundreds of millions of people. According to one estimate, over 330 million people live within 10 km of rivers originating in the snow leopard habitat (Sindorf et al., 2014).

The snow leopard habitat is subject to pervasive human use, predominantly in the form of pastoralism and agro-pastoralism. The snow leopard range in Asia is witnessing rapid transformation through the development of large-scale infrastructure, sedentarisation of nomadic communities, increasing livestock stocking densities and degradation of rangelands. This rapid socio-economic transformation has resulted in an unprecedented anthropogenic footprint in the region and an increase in the over-exploitation of natural resources due to improved access and linkages with consumers and markets outside the region. Over the past two decades, snow leopard habitats have increasingly been subject to mining (Snow Leopard Network, 2014), rearing of commercial livestock such as cashmere goats (Berger et al., 2013), large-scale extraction of non-forest products such as *cordyceps* (Wangchuk & Wangdi, 2015) and tourism. The impacts of climate change have also exacerbated the threats to snow leopards and their habitats. Climate models estimate that by 2070 only 35% of current snow leopard range will remain stable climate refugia and snow leopard habitats will decline by 8–23% and become increasingly fragmented (Forrest et al., 2012; Li et al., 2016).

Only 35%
of current snow leopard range is predicted to remain as stable climate refugia. Snow leopard habitat is expected to decline by 8-23% by 2070 due to climate impacts.

In 2002, conservationists from across the snow leopard range countries came together to consolidate existing knowledge on snow leopards and discuss the next steps in their conservation. The resulting snow leopard survival strategy document synthesized existing knowledge and identified critical threats and gaps in information (McCarthy & Chapron, 2003). The strategy was revised in 2014 (Snow Leopard Network, 2014) to take stock of progress in filling those knowledge gaps, re-evaluate the prevalence of threats to snow leopards and present an actionable way forward for their conservation. The governments of the 12 snow leopard range countries reiterated their commitment to protect snow leopards and their habitats through the 2017 Bishkek Declaration and 2019 Delhi Declaration.

Current knowledge on snow leopards shows that only 14–19% of their range overlaps with Protected Areas (Deguignet et al., 2014), with 40% of those Protected Areas being smaller than a single adult's average home range (Johansson et al., 2016). Conservationists generally agree that land sharing, as opposed to land sparing, is the most viable approach to the long-term conservation of snow leopards (Johansson et al., 2016; Mishra et al., 2010). However, the large interface between pastoral communities and the species often results in conflict, wherein livestock depredation by snow leopards sometimes results in retaliatory killings. It is estimated that between 221 to 450 snow leopards are killed by people annually, with 55% of these being retaliatory killings in response to livestock predation by snow leopards (Nowell et al., 2016).

Only 14-19%
of snow leopard range is protected, with 40% of those protected areas being smaller than a single adults home range

Between 221-450 snow leopards are killed by people annually, 55% of this killing is driven by retaliation for snow leopard predation on livestock

Since a majority of the snow leopard range is comprised of multiple-use landscapes with varying

A biologist installing a camera trap for population estimation of snow leopards in Altai-Sayan, Russia

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degrees of human presence and dependence, it is crucial to understand the scenarios that promote co-existence. Finding opportunities and limits of co-existence requires a multi-disciplinary approach in order to understand the ecological processes, socio-economic factors, drivers of people's tolerance and stewardship of wildlife, political realities and external drivers of change. In this study, we ask whether several decades of accumulated knowledge on snow leopards provides this understanding.

We systematically reviewed published snow leopard research between 1904 and 2020 to examine spatio-temporal trends in research and identify critical gaps in knowledge and future research priorities for effective conservation planning.

OBJECTIVES

Examine trends in snow leopard research over the past 100 years.

Map the spatial extent of the research and identify hotspots of research as well as regions that remain poorly covered.

Identify critical research gaps and suggest areas of future research for effective conservation planning.

METHODS

Literature review, variable identification and coding

LITERATURE REVIEW

We conducted a systematic assessment of peer-reviewed scientific articles dealing with snow leopards, wild ungulates, co-predators and snow leopard habitat. We searched for articles in two comprehensive databases: Google Scholar and the online bibliography of the Snow Leopard Network (www.snowleopardnetwork.org). The search was restricted to articles published until September 2020. From the Google Scholar search, we included articles that contained at least the common/scientific name of the species (Snow Leopard, *Panthera uncia, Uncia uncia*), the common/scientific names of the main wild ungulate prey of the snow leopards i.e. Siberian ibex *(Capra sibirica)*, blue sheep *(Pseudois nayaur)*, Himalayan tahr *(Hemitragus jemlahicus)*, argali *(Ovis ammon)*, marmots *(Marmota* spp) and/or at least one of the following words or phrases: human-wildlife conflict, climate change, livestock depredation, conservation plans, conservation policies, poaching and illegal trade, retaliatory killings, distribution and abundance, disease, pasture management, livestock production, community stewardship of conservation, traditional practices and folklore, traditional ecological knowledge, and Protected Areas.

VARIABLE IDENTIFICATION

We included every single peer-reviewed article from the bibliography of the Snow Leopard Network. While we primarily had only English language journal articles, bilingual articles with English language translations were also included. A total of 336 publications were finally included in the review after removing duplicates and non-peer-reviewed articles. However, studies published in country-specific/regional journals were included for the approximation of the spatial extent of snow leopard range covered by some form of research (n = 15 for publications in Chinese and n = 26 for publications in Russian).

To characterize the research, a list of themes and sub-themes was prepared by screening a random sample of 30 articles based on their research focus, and using the categories of information needs as identified in the Snow Leopard Survival Strategy, 2003 and 2014 (McCarthy & Chapron, 2003; Snow Leopard Network, 2014). We prepared a table of themes and sub-themes, which was reviewed by four independent snow leopard scientists. Their suggestions on the classification of themes and additional research themes for inclusion were incorporated in the final table (see Appendix I).

CODING

The primary authors classified a sub-sample of 30 articles independently and identified and discussed discrepancies until a consensus was reached to ensure consistency in assigning publications to appropriate thematic categories. Following this, the lead author assigned all the 336 publications to one or more themes and sub-themes based on the primary focus of the research. We primarily looked at the abstract, the objectives of the study and results section of the paper to assign it to one or multiple themes. The following information was then also extracted from each article: (1) name(s) of the author(s) (2) year of publication (3) title of the study (4) name of publication (5) study site (6) name of the country (7) geographical coordinates of the study area (8) size of the study area (if provided) (9) key themes and sub-themes examined by the study as outlined in Appendix I. In this way a database of research on snow leopards over the past 100 years was developed.

Mongolian biologists examining a suspected snow leopard rake mark on a tree.

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The coordinates of the studies were extracted where possible and point locations were plotted in a Geographical Information System using the Quantum GIS software (QGIS Development Team, 2017). We then used the Kernel Density Estimation in QGIS to identify hotspots of snow leopard research. While our original intention was to plot the actual polygons of the studies conducted, the information required for such plotting was unavailable for most of the published research and point locations were used instead. We intend to overcome this limitation by releasing an open source online platform called "State of Knowledge in Snow Leopard Range" where authors can add their studies and necessary spatial information to build a live database of snow leopard knowledge across its range.

Biologists taking morphometric measurements of a radio-collared snow leopard in Nepal.

RESULTS

Trends and patterns of research in the snow leopard range

Our review showed an uneven distribution of studies across the snow leopard range with the greatest number of studies occurring across the mountain ranges of Altai (32%), followed by the Tibetan Plateau (19%), Himalayas (18%) and Tian Shan (16%), Pamir Alay (7%), Hindukush (4%), Kunlun Shan (2%) and Karakoram (2%) mountain ranges (Figure 1).

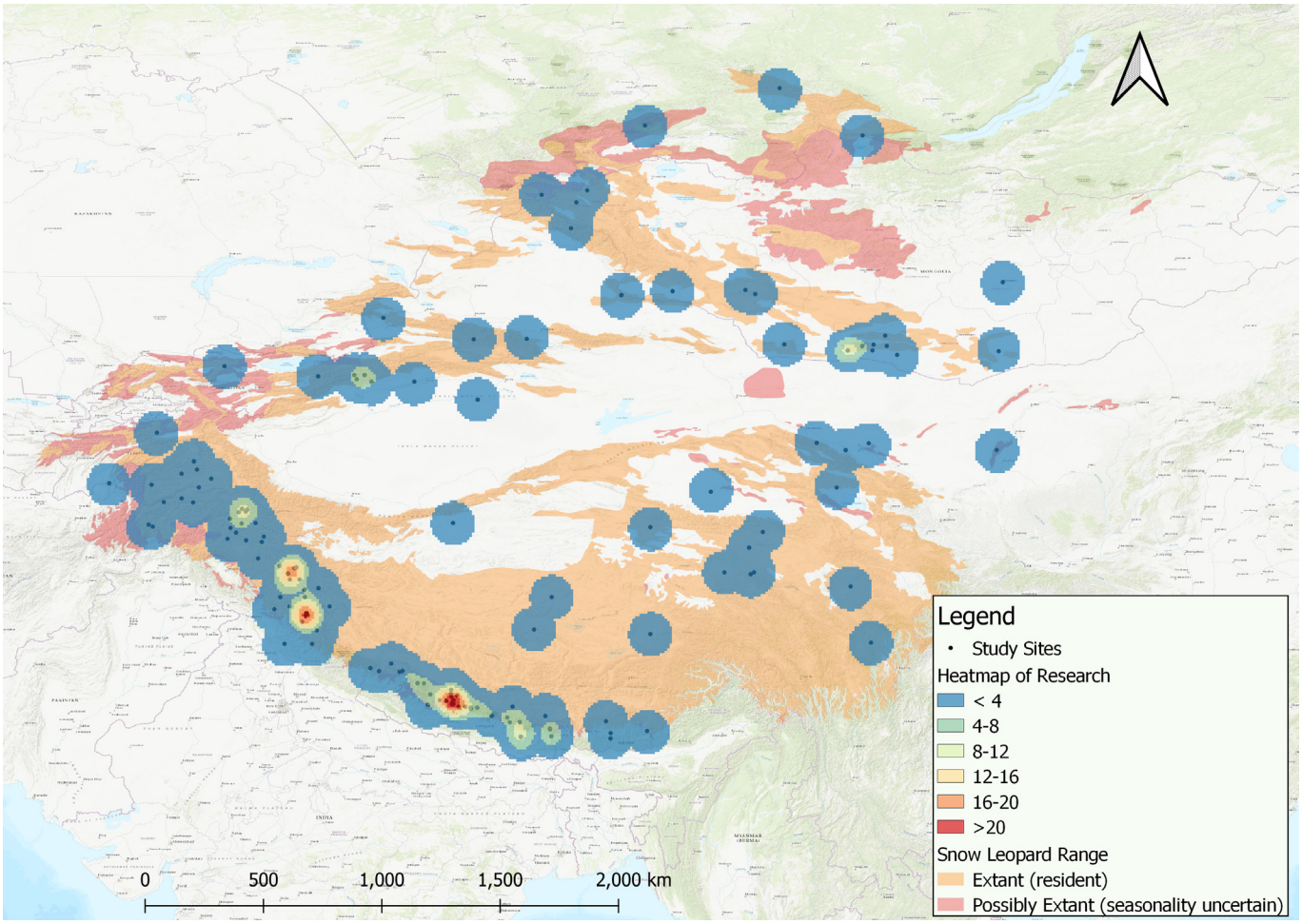

Figure 1. Distribution of research in the snow leopard range (peer-reviewed publications on snow leopards, prey species, co-predators, their habitat and other thematic aspects) from 1904 to 2020. A few hotspots of snow leopard research included Hemis National Park (India), Spiti Valley (India), Annapurna Conservation Area (Nepal) and Tost Mountains (Mongolia). The snow leopard range map was derived from IUCN 2020.

Research across snow leopard range spans more than a century, starting from 1904. The research on snow leopards grew rapidly in the 1970s and has increased exponentially since then (Figure 2).

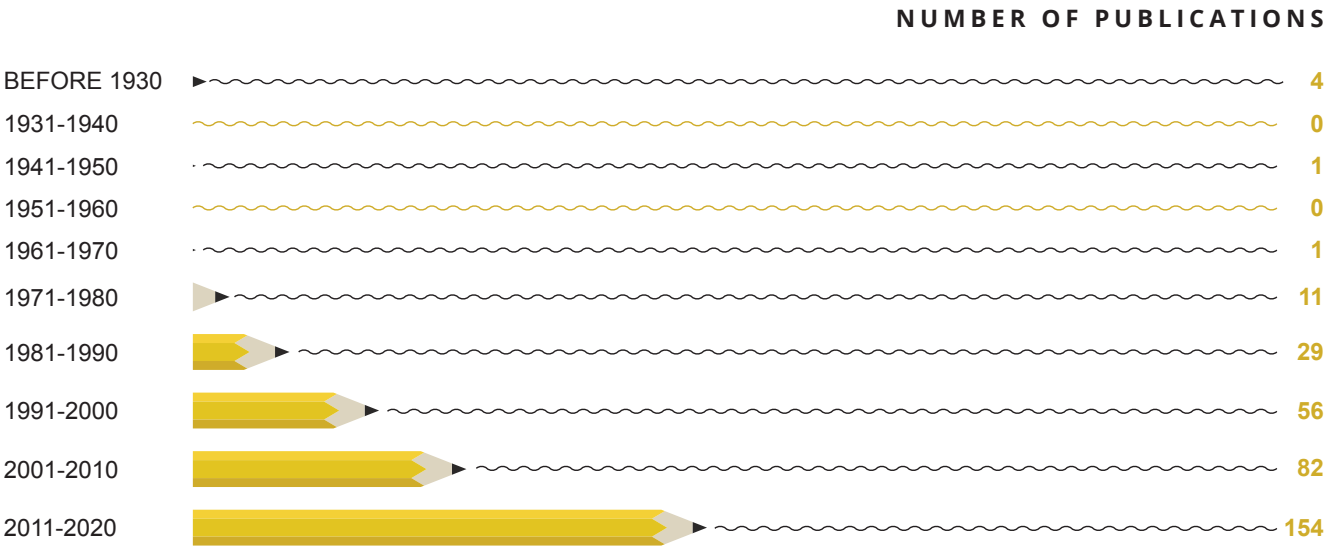

Figure 2. Number of peer-reviewed publications on snow leopards, prey species, co-predators, their habitat and other thematic aspects from 1904 to 2020.

The countries reporting the highest number of studies included Nepal, India, China, Mongolia and Pakistan, in decreasing order (Figure 3). The rest of the range countries had less than 10 published studies each. Multi-country studies were also common in the snow leopard range (n =32).

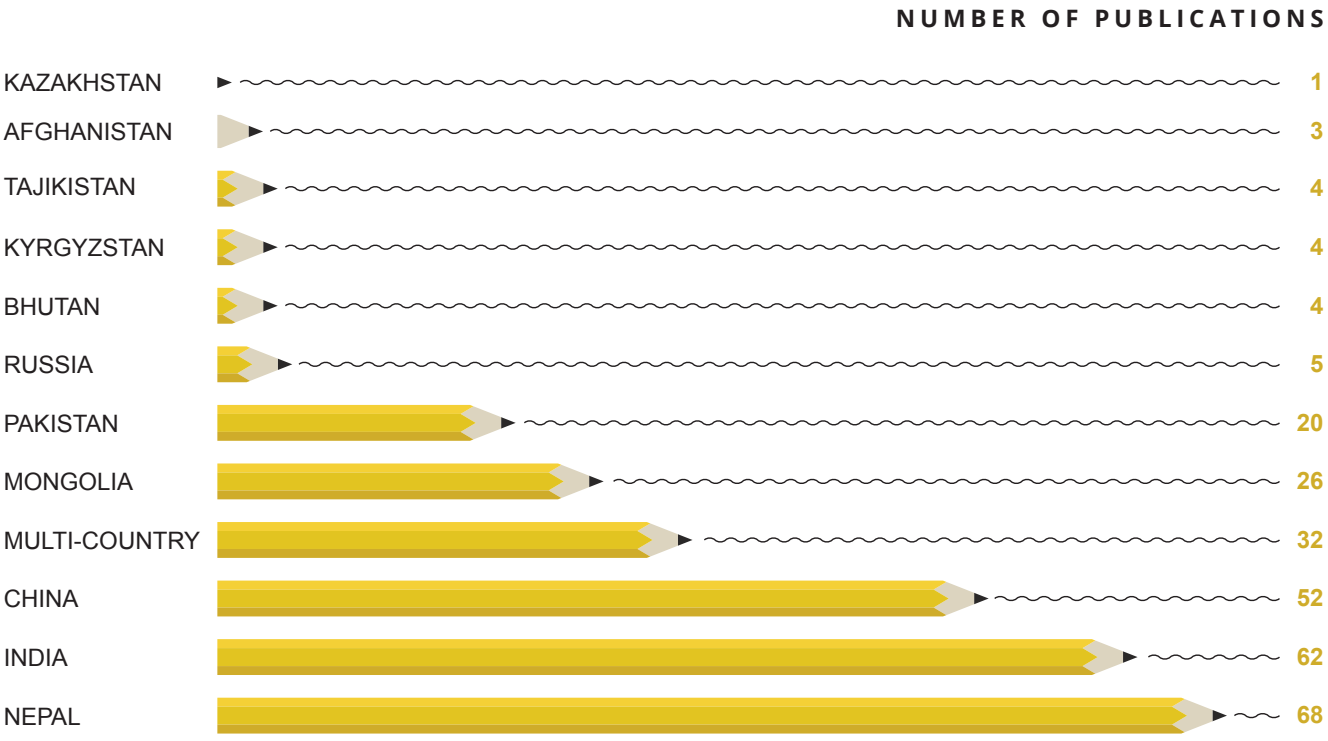

Figure 3. Distribution of snow leopard research across range countries.

There was an evident focus on ecological research which had the highest frequency of papers, followed by human-wildlife conflict and social dimensions of research (see Appendix I for details on various thematic categories of research). Other themes such as direct threats to snow leopards and wild ungulates, conservation plans and policies, threats and rangeland issues, climate change and conservation technology received less attention (Figure 4).

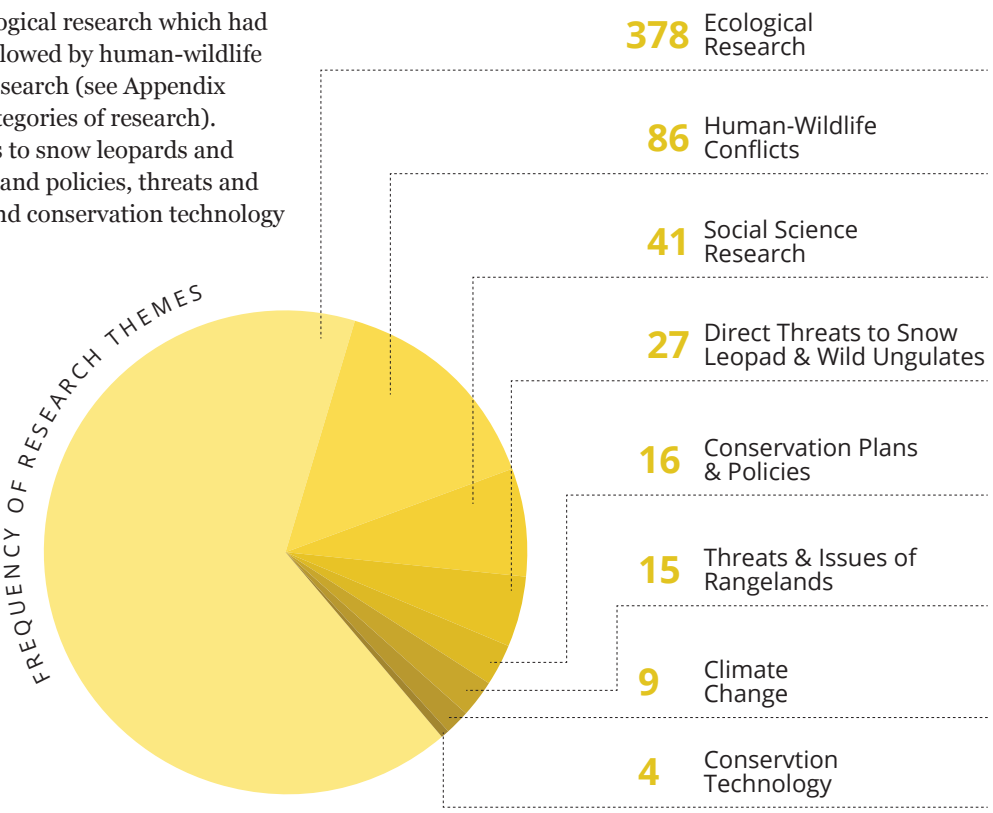

Figure 4. Frequency of various themes of snow leopard research in the snow leopard range from 1904-2020.

While ecological aspects dominated the snow leopard research, a breakdown of ecological research revealed a predominant focus on survey and monitoring with abundance and distribution of snow leopards and wild ungulates being the primary focus of most studies (Figure 5). This was followed by food habit studies, studies on habitat use and selection, molecular ecology, disease ecology, ethology and physiological studies. The majority of disease ecology, ethology and physiological studies were zoo studies.

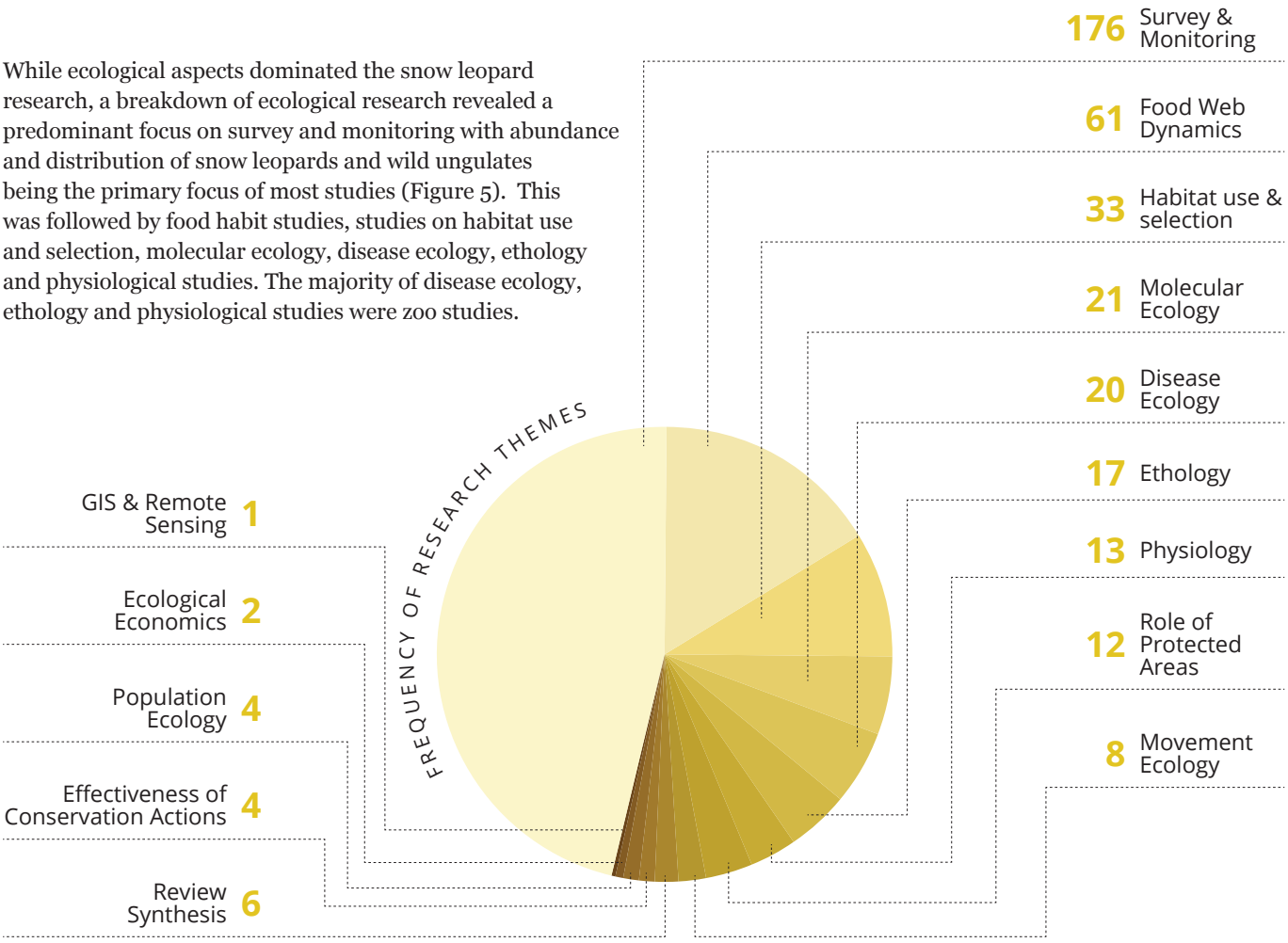

Figure 5. Frequency of research sub-themes within the theme 'ecological research'. Note the predominant focus on surveys (abundance and distribution) and food habit studies.

The distribution of research within the snow leopard range countries mirrored the overall global trends, wherein ecological research remained the focus followed by human-wildlife conflict and socio-ecological dimensions. Nepal, India and China not only had the largest number of research studies but also a greater variety of thematic areas.

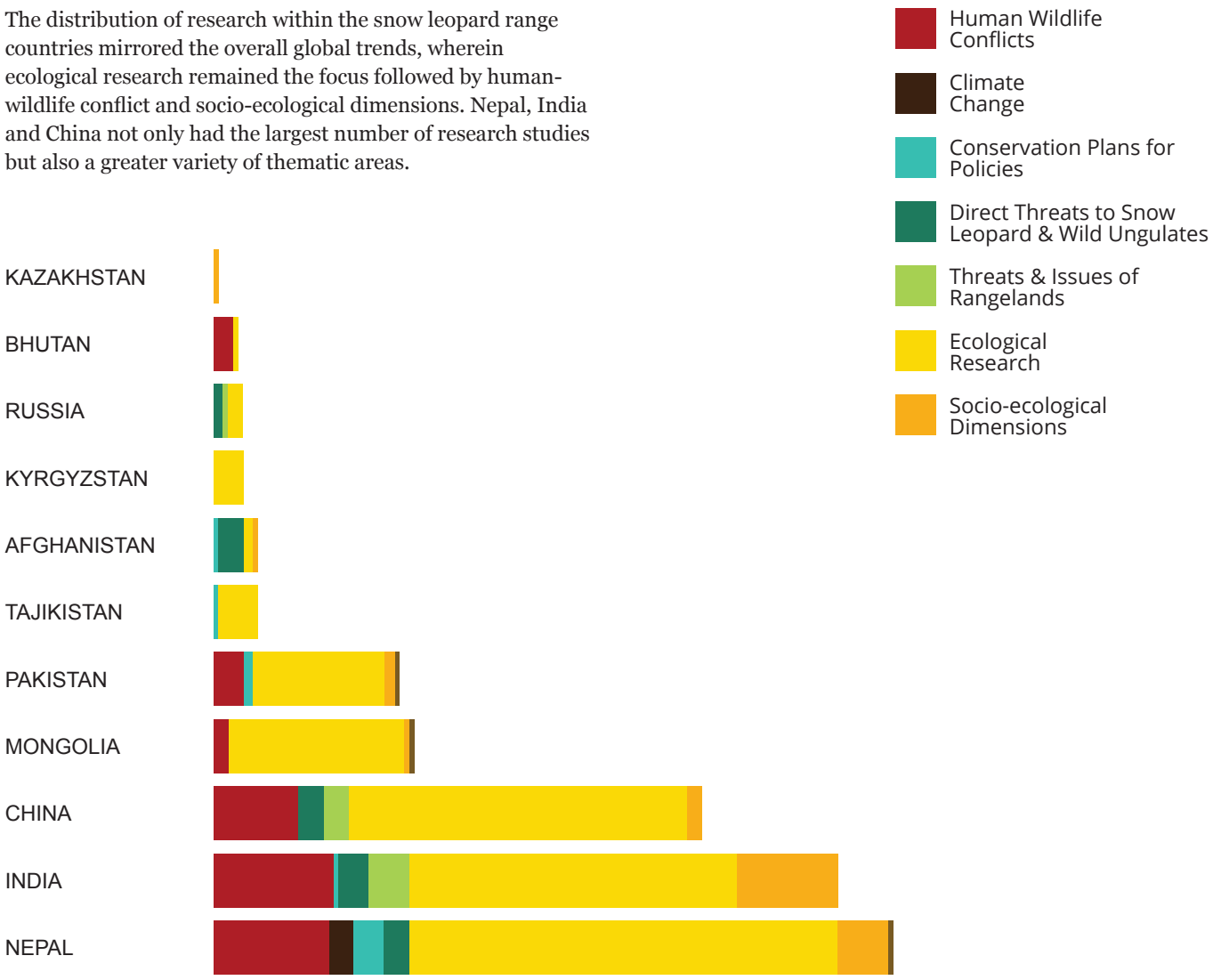

Figure 6. Frequency of publications per theme in each of the snow leopard range countries from 1904-2020.

The spatial extent of snow leopard research in the range countries

The 12 snow leopard range countries encompass a potential snow leopard habitat of approximately 1,776,000 square kilometres (Snow Leopard Working Secretariat, 2013). Of this, approximately 394,819 square kilometres had been subjected to snow leopard research, forming about 22% of the global range (Table 1).

Studies in China, which had the largest proportion of snow leopard range (62%), provided snow leopard information for >270K square kilometres, followed by India, Nepal and Mongolia (each having covered an area exceeding 20,000 square kilometres).

The proportion of area within each country covered by research was highest in Nepal (74%), followed by India (40%), Uzbekistan (39%) and China and Russia (25%).

The spatial spread of snow leopard research showed that India, China and Nepal had the highest number of studies, comprising more than 50 per cent of global research. India, Nepal and Mongolia emerged as hotspots of snow leopard research, indicating intensive long-term studies at specific sites within these countries (Figure 1). Shimshal (Pakistan) and Tomur National Nature Reserve (China) emerged as other hotspots of snow leopard research.

Overall, the spatial analysis indicated that research was restricted to a few hotspots within range countries, revealing large areas of the snow leopard range that received scant research attention.

Table 1. Snow leopard habitat area covered by research, by country, 1904 to 2020. Only studies that provided some approximation of study area were included. Studies published in country specific/regional journals were also included for better approximation of snow leopard range that had seen some form of research/surveys. The estimate of the snow leopard habitat in each range country was from GSLEP (Snow Leopard Working Secretariat, 2013).

RANGE COUNTRY	ESTIMATED SNOW LEOPARD HABITAT (KM^2)	% OF GLOBAL SNOW LEOPARD RANGE	NUMBER OF STUDIES	% OF TOTAL STUDIES	TOTAL AREA COVERED BY RESEARCH	% OF TOTAL COUNTRY RANGE AREA COVERED
China	1,100,000	61.94	40	22	270,625	25
Kyrgyzstan	105,000	5.91	8	4	10,850	10
Mongolia	101,000	5.69	11	6	20,793	21
Tajikistan	100,000	5.63	6	3	8,042	8
Pakistan	80,000	4.50	11	6	8,431	11
India	75,000	4.22	46	25	30,152	40
Russia	60,000	3.38	2	1	14,783	25
Kazakhstan	50,000	2.82	7	4	2,036	4
Afghanistan	50,000	2.82	2	1	1,252	3
Nepal	30,000	1.69	42	23	22,205	74
Bhutan	15,000	0.84	1	1	1,730	12
Uzbekistan	10,000	0.56	9	5	3,920	39
Total	1,776,000	100	185	100	394,819	

Research priorities in the snow leopard range

Considering the research needs identified in the Snow Leopard Survival Strategy as a reflection of global priorities for snow leopard research, 19 of 27 research priorities identified by the Snow Leopard Survival Strategy in 2003 remained unfulfilled in 2014, as shown in the revised snow leopard strategy of 2014 (Table 2). The remaining 8, including hotspots of distribution of snow leopards and wild ungulates, food habits, relationship of snow leopards to other predators, Protected Area coverage of its range, wild ungulate-livestock interactions, analysis of existing laws and policies and methods to alleviate the impact of war, were considered to have adequate research and were no longer identified as research priority areas for the next five years (2014 to 2019).

Overall, 13 of the 27 identified areas of research needs had less than 10 studies each, which included research/information needs that were no longer considered a priority (Table 2). The research themes with less than 10 studies included snow leopard social structure and behaviour, effects of climate change, development of snow leopard monitoring techniques, trends in livestock and human populations, interactions between livestock and wild ungulates, snow leopard home range size and habitat use, causes of livestock depredation, socio-economic profiling of herder communities, analysis of existing policies and laws, trends in snow leopard population, economic valuation of snow leopard habitats, methods to alleviate the impact of war and snow leopard migration and dispersal routes.

Table 2. Research information needs identified in the Snow Leopard Survival Strategy (SLSS), 2003 and 2014 and the proportion of studies that contributed to those needs. Please note that studies can straddle multiple themes and are not mutually exclusive.

SL	RESEARCH OR INFORMATION NEEDS	SLSS 2003	SLSS 2014	RESEARCH PRIORITY FOR THE NEXT FIVE YEARS	TOTAL NO. OF STUDIES UP TO 2020	PROPORTION OF TOTAL
1	Snow leopard migration and dispersal routes	Yes	Yes	Yes	0	0.00
2	Snow leopard population size	Yes	Yes	Yes	22	5.14
3	Snow leopard population trends and factors involved	Yes	Yes	Yes	3	0.70

SL	RESEARCH OR INFORMATION NEEDS	SLSS 2003	SLSS 2014	RESEARCH PRIORITY FOR THE NEXT FIVE YEARS	TOTAL NO. OF STUDIES UP TO 2020	PROPORTION OF TOTAL
4	Agents of habitat degradation and relative impacts	Yes	Yes	Yes	34	7.94
5	Economic valuation of snow leopards	Yes	Yes	Yes	2	0.47
6	Snow leopard-prey relationships	Yes	Yes	Yes	11	2.57
7	Livestock depredation rates	Yes	Yes	Yes	37	8.64
8	Livestock depredation causes	Yes	Yes	Yes	5	1.17
9	Snow leopard home range size and habitat use	Yes	Yes	Yes	6	1.40
10	Snow leopard social structure and behaviour	Yes	Yes	Yes	9	2.10
11	Snow leopard population genetics	Yes	Yes	Yes	21	4.91
12	Snow leopard monitoring techniques development	Yes	Yes	Yes	8	1.87
13	Socio-economic profiling of herder communities	Yes	Yes	Yes	5	1.17
14	Human attitudes to snow leopards	Yes	Yes	Yes	25	5.84
15	Prey population baseline and trends	Yes	Yes	Yes	36	8.41
16	Snow leopard and ungulate disease	Yes	Yes	Yes	20	4.67
17	Snow leopard poaching levels	Yes	Yes	Yes	15	3.50
18	Effects of climate change	No	Yes	Yes	9	2.10
19	Livestock and human population status and trends	Yes	Yes	Yes	7	1.64
20	Snow leopard food habits	Yes	Yes	No	26	6.07
21	Snow leopard distribution and 'hotspots'	Yes	Yes	No	57	13.32
22	Prey species distribution and 'hotspots'	Yes	Yes	No	29	6.78
23	Wild ungulate-livestock interactions (competition)	Yes	Yes	No	7	1.64
24	Snow leopard relationships to other predators	Yes	Yes	No	15	3.50
25	Methods to alleviate impact of war	Yes	No	No	2	0.47
26	Analysis of existing policies and laws	Yes	No	No	5	1.17
27	PA coverage - extent, presentation of habitats	Yes	No	No	12	2.80

Comparative growth of social science and ecological research

There was a steep, exponential rise in ecological research since it began to grow in the 1970s. However, social science research began its growth much later in the 1990s and continued to lag behind ecological research.

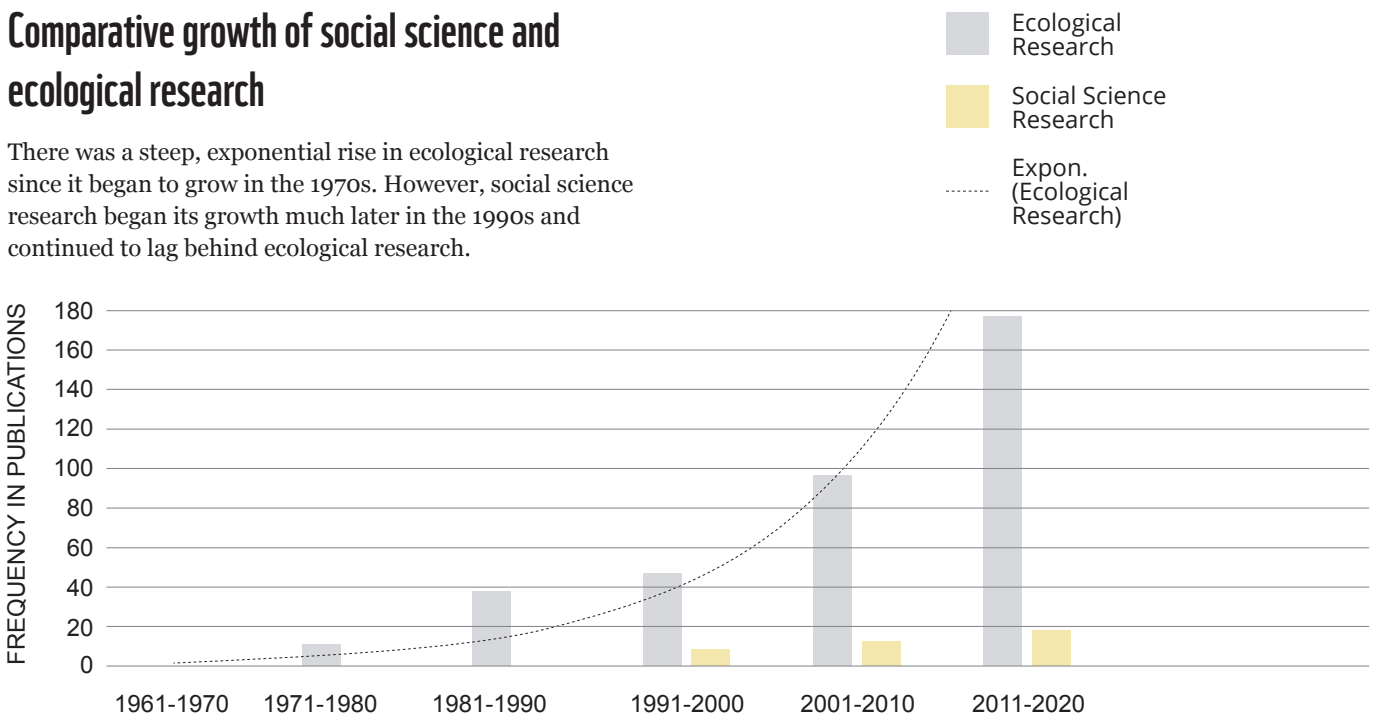

Figure 7. Trends in ecological and social science research across the past six decades. The dotted curve shows the exponential rise in ecological research on snow leopards.

Snow leopard population density estimation

Snow leopard studies focussing on population density estimation using robust field methodologies (camera trapping, genetics, radio-telemetry) and analytical approaches such as spatially explicit capture recapture models (secr) covered an estimated cumulative area of 51,386 square kilometres, or less than 3% of the total geographic range (Table 3).

Pakistan covered the largest geographic area with research enumerating snow leopard populations, followed by Bhutan, Nepal, India, Mongolia, Tajikistan and China. Bhutan had the largest proportion of its snow leopard habitat covered by population density-focussed research (76%) followed by Pakistan (24%) and Nepal (19%). India, Mongolia, Tajikistan, Kyrgyzstan, Russia and China had less than 10% of their range covered, while Uzbekistan, Afghanistan and Kazakhstan had no studies.

A snow leopard scent marking a rocky outcrop in the Western Himalaya, India.

Table 3. Studies estimating snow leopard population density using camera traps, genetics and radio-telemetry, 1916 to 2017. See Appendix II for details of the studies used in this table.

COUNTRY	SNOW LEOPARD HABITAT (KM2)	% OF TOTAL COUNTRY SNOW LEOPARD RANGE AREA	NO. OF STUDIES	ACTUAL AREA COVERED	% OF RANGE AREA COVERED
Bhutan	15000	1	4	11360	75.73
Pakistan	80000	5	1	19000	23.75
Nepal	30000	2	13	5729	19.10
India	75000	4	10	4446	5.93
Mongolia	101000	6	13	3562	3.53
Tajikistan	100000	6	11	2877	2.88
Kyrgyzstan	105000	6	2	1463	1.39

COUNTRY	SNOW LEOPARD HABITAT (KM2)	% OF TOTAL COUNTRY SNOW LEOPARD RANGE AREA	NO. OF STUDIES	ACTUAL AREA COVERED	% OF RANGE AREA COVERED
Russia	60000	3	1	400	0.67
China	1100000	62	9	2549	0.23
Uzbekistan	10000	1	0	0	0.00
Afghanistan	50000	3	0	0	0.00
Kazakhstan	50000	3	0	0	0.00
Total	17,76,000		95	51386	

Evidence for effectiveness of conservation interventions

Evidence for effectiveness of conservation actions on snow leopard research was rare, with just four studies specifically evaluating the results of their conservation actions. Amongst these, one investigated the potential impacts of trophy hunting on snow leopards (Kachel et al., 2017), two examined whether the recovery of wild prey would result in reduced predation of livestock by snow leopards (Bagchi et al., 2019; Suryawanshi et al., 2017) and one tested the efficacy of fencing to protect livestock from snow leopard predation (Samelius et al., 2020). Despite considerable focus on human-wildlife conflict in snow leopard research, the evidence for effectiveness of various conflict mitigation measures was scarce. This was the same for other commonly proposed interventions such as recovery of wild ungulates to reduce livestock predation and various incentives to promote community stewardship of snow leopards.

Livestock secured through a predator proof corral in the Western Himalaya of India. Livestock predation by snow leopards is a major reason for conflict with local communities.

DISCUSSION

RESEARCH PRIORITIES AND GAPS IN KNOWLEDGE

We found that research efforts over the past 100 years cover approximately 22% of the snow leopard range. This was partly due to the rugged terrain in which snow leopards occur and the related logistical challenges of conducting research in the snow leopard range. International borders and hostilities between range countries presented further challenge, with access near transboundary areas difficult.

The coverage of research themes in the snow leopard range was uneven with ecological research receiving major attention, followed by research on human-wildlife conflict and social dimensions of snow leopard research. Several areas with high relevance to conservation management, such as direct threats to snow leopards and wild ungulates, conservation plans and policies, threats and issues of rangelands and climate change received relatively less attention. Even within ecological research, abundance and distribution of snow leopards and wild ungulates comprised the majority of research, especially in the early days. This is perhaps understandable as sheer logistical difficulties in accessing snow leopard habitats precluded long-term research, and rapid surveys focusing on distribution and abundance would have been most feasible. The information provided by the surveys that would be valuable as research was patchy and an accurate assessment of snow leopard abundance and distribution remained elusive. However, in the past two decades, even though research became more diverse, a substantial focus on population size and distribution surveys of snow leopards and prey species continued. Research on other important aspects of snow leopard ecology – such as disease ecology, relationship between livestock, wild ungulates and carrying capacity of rangelands, movement ecology, population dynamics, snow leopard behaviour and impacts of climate change – appeared woefully inadequate for informed conservation planning and management.

In the Anthropocene, humans are constantly shaping the environment and have emerged as the biggest drivers of environmental change (Steffen et al., 2007). The importance of qualitative research in understanding complex conservation problems, therefore, cannot be overemphasized. In-depth research is necessary to understand the relationship between, and impacts of, humans on the natural environment (Rust et al., 2017). Snow leopards share space with local pastoral and agro-pastoral communities across their range and more than 80% is outside of the protected areas (Deguignet et al., 2014). Despite this fact, the relatively slow growth of research in the human dimensions of conservation is worrying and should be a major focus of research for the snow leopard conservation community.

CAN SNOW LEOPARD RESEARCH GUIDE CONSERVATION PLANNING?

Good decision making for conservation planning needs to be founded on rigorous science and reliable information while acknowledging and remedying the uncertainty associated with knowledge (IUCN – SSC Species Conservation Planning Sub-Committee, 2017). The variety of information required for effective conservation planning can be far higher in coupled socio-ecological systems such as multiple-use snow leopard habitats.

Studies on snow leopard-prey relationships, migration and dispersal, social structure and behaviour, demographic parameters, role of interactions between snow leopards and free-ranging dogs and wild and domestic ungulates in disease outbreaks and habitat selection in multiple-use landscapes are critical for developing effective conservation plans, and yet have received relatively poor attention. Several thematic areas of direct conservation relevance such as conservation planning and policy, impacts of habitat fragmentation and degradation on snow leopards and wild ungulates and determinants of social carrying capacity/tolerance for snow leopards have also received very little attention, despite their obvious significance.

A Buddhist monastery and agricultural fields in a multiple use snow leopard landscape.

We argue that diversifying areas of conservation research should be a priority for the conservation community, especially as old threats to snow leopards such as poaching (Nowell et al., 2016) continue unabated and emerging threats such as climate change (Li et al., 2016) and large-scale economic and infrastructure development in High Asia pose a new set of conservation challenges.

LACK OF EVIDENCE LIMITS SNOW LEOPARD CONSERVATION

Despite considerable focus on species distribution and abundance, less than 3% of the snow leopard range has been surveyed using rigorous population-density estimation methods including use of camera traps and genetic tools. While researchers generally agree that current snow leopard numbers are based on the need to extrapolate broadly from knowledge based on 3% of their range, there has been no large-scale effort to rigorously estimate snow leopard populations across their range. This, coupled with the absence of long-term monitoring programmes makes it impossible to evaluate the impact of conservation interventions on the species. Hopefully, the lack of rigorous estimates of population abundance will be gradually remedied by the recently increased focus on national-level population assessments by several range country governments and NGOs. There is also a global focus on large-scale snow leopard population estimates in the form of PAWS (Population Assessment of the World's Snow Leopards) under the umbrella of the GSLEP (Snow Leopard Working Secretariat, 2013).

Another major gap in snow leopard research is the lack of focus on evidence for effectiveness of conservation actions. Our review found just four studies that explicitly evaluated the effectiveness of conservation interventions in the snow leopard range. This indicates another major omission in snow leopard science where the lack of evidence for the effectiveness of a variety of concurrent interventions results in limited decision support for conservation.

FUTURE DIRECTIONS FOR SNOW LEOPARD RESEARCH

The snow leopard conservation community has long known the information required for effective conservation planning of the species. A master list of these needs and potential methods to address them was outlined in detail in the first version of the Snow Leopard Survival Strategy (McCarthy & Chapron, 2003). This was reassessed in 2014 with a full chapter devoted to gaps in knowledge on snow leopard and prey species' ecology and conservation (Snow Leopard Network, 2014). A comparison of the two lists shows that most of the research priorities listed in 2003 remain priority areas, except for food habits, population estimates, snow leopard distribution, prey species distribution, competition between wild prey and livestock, methods to alleviate the impact of war, livestock and human population trends, analysis of existing policies and laws and protected area coverage. Based on our assessment of the coverage of various thematic areas in existing snow leopard research and the conservation requirements of the species, we propose the following areas of research that require urgent attention. This is not an exhaustive list of research needs, but are recommended areas of research that require priority action.

1. Evaluating the effectiveness of conservation actions: An inability to address counterfactual scenarios continues to pose a major challenge to many conservation efforts (Ferraro, 2009; Ferraro & Pattanayak, 2006) and snow leopard conservation is no exception. Success in conservation projects remains poorly defined with outcomes of conservation interventions seldom documented and quantitative empirical evidence of the impact of conservation actions rarely collected. The lack of appropriate performance evaluation in conservation programmes, especially the failure to link conservation outcomes to goals, is increasingly being scrutinized (Kleiman et al., 2000; McDonald-Madden et al., 2009). An evidence-based conservation approach for snow leopards should be a priority for conservation organisations and snow leopard range country governments.

2. Monitoring snow leopards and prey species: The tools and techniques used to estimate population-density of elusive species have seen considerable development, especially in the past two decades. Camera trap surveys and genetic assessments have become cheaper and statistical approaches such as mark-recapture and spatially-explicit capture-recapture models (Borchers & Efford, 2008; Gopalaswamy & Royle, 2012) now enable robust data analysis. Snow leopards and prey species need to be enumerated and monitored using a strong set of scientifically accepted methods, with collaborative multi-stakeholder monitoring programmes set up in key landscapes. The 23 GSLEP priority landscapes would provide a good starting point. Long term monitoring programmes in priority landscapes can provide valuable information on the trends in population of snow leopards, wild ungulates and livestock as well as the potential factors driving the change in the population of species of interest and the impact of threats such as climate change and habitat degradation. Combined, this information can provide critical insights for informed conservation decisions.

3. Integrating human dimensions into conservation: Michael E. Soule defined conservation biology as a crisis discipline and placed social sciences firmly in its ambit (Soule, 1985). In an increasingly complex and human-dominated world, social science research, coupled with natural science research, can offer unique insights into conservation problems which, in turn, can inform robust and effective conservation policies (Bennett et al., 2016). Given the large interface between people and snow leopards, it is crucial to integrate human dimensions into snow leopard conservation research.

4. Disease: Aspects of snow leopard disease ecology, outbreaks of disease in wild ungulate populations and transfer of disease between wild ungulates and livestock have received woefully inadequate attention (Snow Leopard Network, 2014). Most of our knowledge about the diseases affecting snow leopards comes from zoo studies. However, four radio-collared snow leopards were recently reported dead in South Gobi, possibly due to infectious disease (Esson et al., 2019), while disease outbreaks in wild ungulate populations have been reported from Pakistan, Tajikistan and India with significant mortalities. These examples illustrate our lack of knowledge about disease prevalence, outbreak and transmission in the wild and they call for the establishment of surveillance and monitoring systems in important snow leopard landscapes (Snow Leopard Network, 2014). This research should be conducted as part of a One Health approach that brings together human, wildlife and ecosystem health as an essential part of efforts to prevent further emerging infectious diseases, such as the globally devastating virus causing COVID-19.

5. Spatial ecology: Snow leopard habitats show tremendous diversity owing to spatial variation in the distribution of resources and other biotic and abiotic factors across its vast range in High Asia. A multi-scale assessment of how variation in the distribution of resources, threats and abiotic factors affects snow leopard population density, habitat use and connectivity is fundamental to developing landscape-scale conservation plans for snow leopards and should be prioritized.

6. Impacts of climate change and infrastructure development: Some of the more recent predictive models of climate change indicate that more than a third of snow leopard habitat areas might become unsuitable for the cat if current climate change trends continue (Li et al., 2016). This indicates the fragility of High Asia in the face of climate change, which is expected to negatively impact not only its biodiversity but also the livelihoods of local communities. This, coupled with large-scale infrastructure development such as mining, mega-dams and roads, is expected to further fragment and degrade the habitat. While the exact effects of climate change are difficult to predict, it is certain to have an overarching influence by impacting critical ecosystem processes and functions. Therefore, it is essential to develop a better understanding of the possible impacts of climate change and implement effective adaptation and

mitigation strategies. This could involve multinational efforts to protect future climate refugia for snow leopards and implement the necessary mitigation and adaptation measures to reduce the impact of climate change on habitats and prevent potential maladaptations.

7. Rangeland ecology: One of the major causes of conservation conflicts in the snow leopard range is the difficulty of reconciling the contrasting needs of livestock herding and wildlife conservation (Du Toit et al., 2010). So far, initiatives that attempt to reconcile these objectives in multiple-use rangelands seem to have had little success, being severely limited in scope and scale. The management of rangelands thus continues arbitrarily, due to the lack of coordination and understanding amongst stakeholders and the absence of a unified framework for snow leopard conservation.

   Across most rangelands, wildlife population densities have been suppressed due to hunting for meat and the wildlife trade, competition with livestock and retaliatory killing of carnivores for livestock depredation. It is evident that rangelands form the bedrock for both livestock herding and wildlife conservation, yet our ecological understanding of these systems remains undeveloped.

   Rangelands are undergoing tremendous changes, with climate change expected to increase aridity, leading to widespread desertification and impact on human livelihoods. Large-scale fencing, such as in the Tibetan Plateau, is becoming a barrier to the free movement of wildlife and the privatisation of rangelands is forcing nomads to settle (Yan & Wu, 2005). An ill-conceived policy, that resulted in the large-scale poisoning of plateau pikas, impacted the percolation of water with potentially severe negative impacts on the hydrological functions of large watersheds in the Qinghai-Tibetan plateau (Wilson & Smith, 2015). As economic development in Asia catches up with other regions of the world, the demand for animal products such as dairy and meat is expected to fuel further growth of the livestock industry (Delgado, 2003; Dong, 2006). In Mongolia, herders engaged in community-based rangeland management (CBRM) have been found to be significantly more proactive in addressing resource management issues and combining innovative and traditional rangeland management practices than their counterparts not involved in CBRM (Ulambayar et al., 2017). In the Spiti valley in India, a community-based livestock-free reserve wherein communities were compensated for lost grazing potential through direct cash payments, reported a five-fold increase in blue sheep populations over a decade (Mishra et al., 2016). Another study found that livestock production and snow leopard conservation were compatible, up to certain thresholds of livestock densities (Sharma et al., 2015). These examples highlight the importance of targeted research in not only understanding the impact of conservation interventions, but in also identifying the opportunities and limits of reconciling livestock production goals with wildlife conservation. Research must focus on understanding the opportunities and challenges of maintaining rangelands as functional ecosystems that can support humans, their livestock and wildlife populations. This requires exploring and implementing ideas that promote ecological harmony in these unique socio-ecological areas.

CONCLUSIONS

Our review suggests that despite an exponential increase in snow leopard research over the past two decades, several important areas remain poorly understood. While research on snow leopard abundance and distribution received a major share of attention, we still do not have reliable estimates of snow leopard abundance across the larger part of the snow leopard range and neither has its distribution been mapped accurately. There is an urgent need to diversify the agenda for snow leopard research, with an enhanced focus on spatial ecology of snow leopards in multiple-use landscapes, disease ecology, impacts of climate change, its population dynamics, the relationships between people, livestock, wild ungulates, snow leopards and rangelands and the impacts of infrastructure development on snow leopard habitat selection and use. The social dimension of research in snow leopard range requires a major impetus and should be one of the top priorities.

Our review also highlights the sobering lack of empirical evidence on a variety of conservation interventions that continue to be recommended and employed with limited evidence of their efficacy. This is specifically true for interventions on mitigating human-wildlife conflict such as predator-proof corrals, improved livestock guarding practices, efforts to enhance wild ungulate prey to reduce livestock predation by snow leopards, recommendations to increase protected area coverage and incentives and/or conservation awareness programmes to enhance the tolerance of local communities towards snow leopards.

Finally, based on our review, we recommend areas of snow leopard research that require increased investment and focus to ensure that snow leopard conservation is informed by adequate knowledge of a diverse array of conservation problems, is evidence-based and can meet the challenges of reconciling the needs of people and wildlife in the high mountains of Central and South Asia.

Snow leopard habitat in the Western Himalaya, India

LIMITATIONS

Our review only examined the peer-reviewed English language journal publications and therefore excludes a large quantity of non-English or unpublished information. For example, several authors in the snow leopard range countries, predominantly China, Russia, Kyrgyzstan, Uzbekistan and Kazakhstan, publish in Chinese and Russian language journals which we have not included in our review. The exclusion of this work is likely to have affected our results, specifically in the number of publications attributed to these countries as well as the assessment of the geographical coverage of snow leopard research.

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APPENDIX I

Coded themes of snow leopard research with branched sub-themes for data analysis. Themes are coded alphabetically and subthemes coded as F, fall under ecological research.

THEMES	SUB-THEMES	CODE
Human-wildlife conflict	Attitude, perception & behaviour of local communities	A1
	Factors responsible for HWC	A2
	HWC mitigation measures and strategies	A3
	Livestock depredation & associated costs	A4
	Hidden costs of conflict	A5
	Loss of life, injuries and property damage	A6
	Crop/orchard loss by wild ungulates	A7
Climate change	Impact of climate change on snow leopards & prey	B1
	Impact of climate change on local communities	B2
	Climate modelling	B3
	Climate adaptation & mitigation	B4
Conservation plans & policies	International/national/landscape conservation plans	C1
	International/national policies/effectiveness analysis	C2
	Trans-boundary issues and cooperation for Protected Areas	C3
	Relationship between locals and management bodies	C4
	Legal frameworks (CITES, CBD, CMS etc.)	C5
	Trophy hunting	C6
Direct threats to snow leopards and wild ungulates	Poaching of snow leopard & illegal trade	D1
	Collection for zoos	D2
	Reduction of natural prey by illegal and unregulated hunting or legal hunting	D3
	Direct killings in retaliation for livestock loss	D4
	Free-ranging dogs	D5
	Impact of war and unrest	D6
Threats and issues of rangelands	Overstocking of rangelands and impact of livestock grazing	E1
	Linear infrastructure and mining	E2
	Collection of medicinal plants (including cordyceps)	E3
	Unregulated tourism, urbanization, military infrastructure, dams	E4
	Rangeland systems and dynamics	E5
Survey and monitoring	Description and morphological characteristics of snow leopard and wild ungulates	F1
	Snow leopard distribution & hotspots	F2
	Snow leopard population density estimates	F3
	Prey species distribution & hotspots	F4
	Prey species population density estimates	F5
	Snow leopard monitoring techniques	F6
	Ungulate monitoring techniques	F7
	Population and distribution of co-predators	F8
	Livestock population and change	F9

THEMES	SUB-THEMES	CODE
Population ecology	Snow leopard demography (population dynamics, survival, and mortality)	F10
	Wild ungulates demography (population dynamics, survival, and mortality)	F11
Ethology	Snow leopard social structure and behaviour	F12
	Wild ungulate social structure and behaviour	F13
Movement ecology	Migration and dispersal routes (snow leopard)	F14
	Home range size and movement patterns (snow leopard)	F15
	Migration and dispersal routes (wild ungulates)	F16
	Home range size and movement patterns (wild ungulates)	F17
Food web dynamics	Food habits of snow leopards	F18
	Snow leopard-prey relationships	F19
	Snow leopard co-predator food habits & overlaps	F20
	Competition between livestock and wild prey	F21
	Ungulate/prey species foraging strategies	F22
Ecological economics	Economic valuation of snow leopard mountain ecosystems & PES	F23
Habitat use and selection	Snow leopard habitat use and selection	F24
	Wild ungulates habitat use and selection	F25
	Habitat use and selection by co-predators	F26
Effectiveness of conservation actions	Evaluate the effectiveness of conservation actions	F27
Role of Protected Areas	Role of Protected Areas, land sparing vs. land sharing	F28
Molecular ecology	Connectivity, corridors and genetic exchange	F29
	Genetics-based population assessments	F30
	Demographics and metapopulation dynamics	F31
	Snow leopard genetics, species identification, genetic diversity	F32
Disease ecology	Disease of snow leopard, co-predators and wild ungulates	F33
	Disease transmission between snow leopards and livestock	F34
	Disease transmission between snow leopards and free-ranging dogs	F35
Physiology	Physiological studies in captivity, capture and immobilization response	F36
GIS & remote sensing	GIS/remote sensing assessments of habitat, corridors, resistance surfaces etc.	F37
Review/Synthesis	Review of status of snow leopard's conservation and ecology	F38
Human dimensions of conservation	Livestock and pasture management strategies	G1
	Community stewardship of conservation (cultural, resource management, religious)	G2
	Human nature relationships, cultural, totemic, symbolism of snow leopards	G3
	Traditional governance institutions and resource management	G4
	Traditional practices and folklore in snow leopard conservation	G5
	Conservation conflicts (multiple dimensions)	G6
	Community engagement protocols & participatory mechanisms supporting decision-making	G7
	Integration of traditional knowledge and science (focus on conservation action)	G8
	Livelihood optimisation	G9
	Sacred site protection and management	G10
	Socio-economics, transition and changes in herder communities	G11
Conservation technology	Radio collars, camera traps, drones and other wildlife monitoring technology	H1

APPENDIX II

List of studies estimating global snow leopard populations using camera traps and genetic analysis.

BLANK	TITLE	COUNTRY	YEAR	LOCATION	AREA (KM2)	SURVEY METHOD	MINIMUM NUMBER	ESTIMATE	DENSITY PER (KM2)	ABUNDANCE METHOD	DENSITY METHOD	REMARKS
(DoFPS, 2016)	National snow leopard survey of Bhutan 2014-2016 [Phase II]: Camera trap survey for population estimation.	Bhutan	2016	Jigme Khesar Strict Nature Reserve, Paro Territorial Divison, Jigme Dorji National Park, Wangchuk Centennial National Park, Bumdeling Wildlife Sanctuary	11360	Camera traps and genetic analysis	63	96	1.08	SECR	SECR	Report
(Wangda et al., 2016)	Population status and distribution of Snow Leopard in Wangchuck Centennial National Park in Bhutan.	Bhutan	2016	Wangchuck Centennial National Park-Central Park Range	797	Camera Traps	9	9 to 11	2.39	CMR	Bayesian SECR	Report
(Wangda et al., 2016)	Population status and distribution of Snow Leopard in Wangchuck Centennial National Park in Bhutan.	Bhutan	2016	Wangchuck Centennial National Park-Western Park Range	621	Camera Traps	7	5 to 17	3.36	CMR	Bayesian SECR	Report
(Ming et al., 2006)	Camera trapping of snow leopards for the photo capture rate and population size in the Muzat valley of Tian Shan Mountains.	China	2006	Muzat Valley	1000	Camera Traps	5	5 to 8	2.0 to 3.2	NA	Buffer strip based	Journal

BLANK	TITLE	COUNTRY	YEAR	LOCATION	AREA (KM2)	SURVEY METHOD	MINIMUM NUMBER	ESTIMATE	DENSITY PER (KM2)	ABUNDANCE METHOD	DENSITY METHOD	REMARKS
(K. P. McCarthy et al., 2008)	Assessing Estimators of Snow Leopard Abundance	China	2008	Tomur	NI	Genetic analysis	9	NI	NI	NA	NA	Journal
(K. P. McCarthy et al., 2008)	Assessing Estimators of Snow Leopard Abundance.	China	2008	Tomur	813	Camera Traps	4	6(SE= 5.35)	0.74	CR	Buffer strip based	Journal
(Alexander et al., 2015)	Face Value: Towards Robust Estimates of Snow Leopard Densities.	China	2015	Qilianshan National Nature Reserve	480	Camera Traps	20	20-36	3.31 (SE = 1.01)	Bayesian SECR	Bayesian SECR	Journal
(Alexander et al., 2016)	A granular view of a snow leopard population using camera traps in Central China.	China	2016	Qilianshan National Nature Reserve	375	Camera Traps	17 to 19	20 to 36	1.46 to 3.29	Bayesian SECR	Bayesian SECR	Journal
(Chen et al., 2016)	Status and conservation of the Endangered snow leopard Panthera uncia in Qomolangma National Nature Reserve, Tibet.	China (Tibet)	2016	Zhalong	112	Camera Traps	2	NI	NI	Minimum number of individuals	NI	Journal
(Chen et al., 2016)	Status and conservation of the Endangered snow leopard Panthera uncia in Qomolangma National Nature Reserve, Tibet.	China (Tibet)	2016	Rongxia	96	Camera Traps	2	NI	NI	Minimum number of individuals	NI	Journal
(Chen et al., 2016)	Status and conservation of the Endangered snow leopard Panthera uncia in Qomolangma National Nature Reserve, Tibet.	China (Tibet)	2016	Riwu	48	Camera Traps	3	NI	NI	Minimum number of individuals	NI	Journal

BLANK	TITLE	COUNTRY	YEAR	LOCATION	AREA (KM2)	SURVEY METHOD	MINIMUM NUMBER	ESTIMATE	DENSITY PER (KM2)	ABUNDANCE METHOD	DENSITY METHOD	REMARKS
(Jackson et al., 2006)	Estimating Snow Leopard Population Abundance Using Photography and Capture–Recapture Techniques.	India	2005	Rumbak watershed, Hemis National Park	71	Camera Traps	6	NI	8.49 (SE = 0.22)	CR	Buffer strip based	Journal
(Jackson et al., 2006)	Estimating Snow Leopard Population Abundance Using Photography and Capture–Recapture Techniques.	India	2005	Rumbak watershed, Hemis National Park	135	Camera Traps	6	NI	4.45 (SE = 0.16)	CR	Buffer strip based	Journal
(R. K. Sharma et al., 2015)	Does livestock benefit or harm snow leopards?	India	2015	Upper Spiti Landscape	4000	Camera Traps	24	NI	NI	NI	NI	Journal
(Suryawanshi et al., 2017)	Impact of wild prey availability on livestock predation by snow leopards.	India	2017	Gya	300	Genetic analysis	4	5	1.66	CR	Naïve Estimate	Journal
(Suryawanshi et al., 2017)	Impact of wild prey availability on livestock predation by snow leopards.	India	2017	Lossar	219	Genetic analysis	1	1	0.45	CR	Naïve Estimate	Journal
(Suryawanshi et al., 2017)	Impact of wild prey availability on livestock predation by snow leopards.	India	2017	Pin	270	Genetic analysis	2	2	0.74	CR	Naïve Estimate	Journal
(Suryawanshi et al., 2017)	Impact of wild prey availability on livestock predation by snow leopards.	India	2017	Tabo	341	Genetic analysis	4	4	1.17	CR	Naïve Estimate	Journal
(Suryawanshi et al., 2017)	Impact of wild prey availability on livestock predation by snow leopards.	India	2017	Kibber	411	Genetic analysis	7	8	1.94	CR	Naïve Estimate	Journal
(Suryawanshi et al., 2017)	Impact of wild prey availability on livestock predation by snow leopards.	India	2017	Lingti	240	Genetic analysis	7	8	3.3	CR	Naïve Estimate	Journal

BLANK	TITLE	COUNTRY	YEAR	LOCATION	AREA (KM2)	SURVEY METHOD	MINIMUM NUMBER	ESTIMATE	DENSITY PER (KM2)	ABUNDANCE METHOD	DENSITY METHOD	REMARKS
(R. K. Sharma et al., 2020)	Spatial variation in population-density, movement and detectability of snow leopards in a multiple-use landscape in Spiti Valley, Trans-Himalaya.	India	2020	Upper Spiti Landscape	950	Camera Traps	16	25 (20 to 38)	0.49 (0.23 to 1.08)	SECR	SECR	Preprint
(K. P. McCarthy et al., 2008)	Assessing Estimators of Snow Leopard Abundance.	Kyrgyzstan	2008	Jangart	808	Camera Traps	5	7(SE = 3.62)	0.87	CR	Buffer strip based	Journal
(K. P. McCarthy et al., 2008)	Assessing Estimators of Snow Leopard Abundance.	Kyrgyzstan	2008	SaryChat	655	Camera Traps	1	1	0.15	CR	Buffer strip based	Journal
(Mccarthy et al., 2010)	Preliminary results of a long-term study of snow leopards in South Gobi, Mongolia.	Mongolia	2010	South Gobi	1300	Camera Traps	15	9 to 16	NI	CR	NI	Journal
(Janečka et al., 2011)	Comparison of noninvasive genetic and camera-trapping techniques for surveying snow leopards.	Mongolia	2011	Gobi Desert	264	Camera Traps	4	4(4 to4)	1.5	CR	Buffer strip based	Journal
(Janečka et al., 2011)	Comparison of noninvasive genetic and camera-trapping techniques for surveying snow leopards.	Mongolia	2011	Gobi Desert	314	Genetic analysis	16	16 to 19	4.9 to 5.9	CR	Buffer strip based	Journal
(K. Sharma et al., 2014)	Vigorous Dynamics Underlie a Stable Population of the Endangered Snow Leopard Panthera uncia in Tost Mountains, South Gobi, Mongolia.	Mongolia	2014	Tost	1684	Camera Traps	14	14 to 21	NI	CR	NI	Journal

BLANK	TITLE	COUNTRY	YEAR	LOCATION	AREA (KM2)	SURVEY METHOD	MINIMUM NUMBER	ESTIMATE	DENSITY PER (KM2)	ABUNDANCE METHOD	DENSITY METHOD	REMARKS
(Conradi, 2006)	Non-invasive sampling of snow leopards (Uncia uncia) in Phu valley, Nepal.	Nepal	2006	Phu Valley	266	Genetic analysis	9	13 (9 to 18)	NI	CR	NI	Masters Thesis
(Ale et al., 2014)	On the status of Snow Leopard Panthera uncia (Schreber, 1775) in Annapurna, Nepal.	Nepal	2014	Annapurna Conservation Area	75	Camera Traps	3	NI	NI	Minimum number of individuals	NI	Journal
(Aryal et al., 2014)	Blue sheep in the Annapurna Conservation Area, Nepal: Habitat use, population biomass and their contribution to the carrying capacity of snow leopards.	Nepal	2014	Annapurna Conservation Area	995	Prey Biomass	19	19	1.6	Prey Biomass	Naïve Estimate	Journal
(Chetri et al., 2019)	Estimating snow leopard density using fecal DNA in a large landscape in north-central Nepal.	Nepal	2019	Annapurna-Manaslu	4393	Genetic analysis	34	144(101 to 214)	0.95(0.1 to 1.9)	SECR	SECR	Journal
(Nawaz & Hameed, 2015)	Research Update 2008-2014. Snow leopard program, Pakistan.	Pakistan	2015	Fifteen different sites across snow leopard range	19000	Genetic analysis	23	NI	NI	Minimum number of individuals	NI	Report
(Poyarkov et al., 2020)	Assurance of the existence of a trans-boundary population of the snow leopard (Panthera uncia) at Tsagaanshuvuut – Tsagan-Shibetu SPA at the Mongolia–Russia border.	Russia	2020	Tsagan-Shibetu	400	Genetic analysis	37	NI	NI	Minimum number of individuals	NI	Journal
(Diment et al., 2012)	First biodiversity survey of Zorkul reserve, Pamir Mountains, Tajikistan.	Tajikistan	2012	Zorkul Reserve	877	Camera Traps	4	NI	NI	Minimum number of individuals	NI	Journal

BLANK	TITLE	COUNTRY	YEAR	LOCATION	AREA (KM2)	SURVEY METHOD	MINIMUM NUMBER	ESTIMATE	DENSITY PER (KM2)	ABUNDANCE METHOD	DENSITY METHOD	REMARKS
(Kachel et al., 2017)	Investigating the potential impact of trophy hunting of wild ungulates on snow leopard Panthera uncia conservation in Tajikistan.	Tajikistan	2017	Murghab Hunting Company concession	1000	Camera Traps	14	NI	0.74 (SD = 0.11)	NI	Bayesian SECR	Journal
(Kachel et al., 2017)	Investigating the potential impact of trophy hunting of wild ungulates on snow leopard Panthera uncia conservation in Tajikistan.	Tajikistan	2017	Madiyan unmanaged area	1000	Camera Traps	6	NI	0.46 (SD = 0.20)	NI	Bayesian SECR	Journal

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