Mitigating Human-Wildlife Conflict: social and ecological dimensions of snow leopard-livestock conflict in Shey Phoksundo National Park

by

Caitlin Laidlaw

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Human-wildlife conflict is one of the world's leading conservation challenges. Carnivores are often found at the forefront of these conflicts with humans, and livestock depredation as a leading cause of conflict between large carnivores and humans across the world. Such is the case for the snow leopard and remote communities in western Nepal. Livestock depredation threatens both the livelihood of these communities and the conservation of the snow leopard. Shey Phoksundo National Park provides the ideal case study to examine this conflict as little research has been conducted on the locations of livestock depredation in this region nor the attitude of local communities to this large carnivore. This research has two objectives. The first is to use a spatial lens to investigate the hotspots of livestock depredation by snow leopards and identify the most significant drivers of these locations. The second is to identify the attitudes of local communities towards snow leopards and highlight any underlying drivers of these attitudes.

Fieldwork for this research involved five weeks of trekking in Shey Phoksundo National Park. Quantitative surveys (n = 105) were used to identify the characteristics and locations of livestock depredation. Through a novel approach of predation risk modelling in Maxent, I examined the relative risk of livestock depredation to identify the conflict hotspots where livestock are most vulnerable to snow leopard depredation. In addition, I explored the underlying landscape features that contribute to this increased vulnerability. The landscape features that had the greatest contribution to the relative risk of livestock depredation from most to least are distance to grassland, distance to large rivers, distance to village, elevation,

distance to roads, distance to cliffs, and distance to rock land cover. The final predation risk model proved robust and followed the best practices of modern Maxent applications by addressing common critiques of this modelling process.

The quantitative surveys were also designed to investigate the attitudes of local communities towards the snow leopard. Attitude was investigated as a whole and determined that there is an overall positive attitude towards snow leopards. However, when split into two distinct geographical regions of lower and upper Dolpo, upper Dolpo proved to hold more negative attitudes. Next, I explored the potential determinants of attitude towards snow leopards through the development of a composite attitude score and applying general linear models to a variety of hypothesized explanatory variables. The top performing model indicated that a combination of gender, years of education, geographic region, number of external supports received, and perception of the change in external supports provided by organizations, best explained attitude towards snow leopards.

This thesis then presents the current state of conflict resolution efforts taking place in Shey Phoksundo National Park. It provides a review of the strategies in place at time of data collection which included four predator proof night corrals funded by WWF Nepal and a government relief scheme to financially compensate livestock owners when their livestock are killed by snow leopards. Additional conflict resolution efforts are highlighted such as tourism, animal husbandry strategies, and cultural beliefs. Qualitative notes captured during the surveys are used to highlight current community perceptions of each of these resolution efforts. Following this discussion, this thesis then looks towards the future of conflict resolution in

Shey Phoksundo National Park. Guided by the quantitative and qualitative insights gained from this research and analysis, I conclude by offering potential management implications that discuss how to strengthen current conflict resolution efforts, as well as provide insights on the potential benefits for the implementation of new strategies.

This thesis demonstrates the importance of approaching human-wildlife conflict with an interdisciplinary lens, as it can offer a more holistic understanding of pathways to coexistence.

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Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction and Research Context

1.1 Background

The turn of the twentieth century brought global recognition to the importance of finding a balance between biodiversity conservation and economic development in the name of sustainable development. Among the world's greatest conservation challenges that are rooted in finding this balance is human-wildlife conflict. Human-wildlife conflict is broadly understood as an interaction between humans and wildlife where one has a negative impact on the other (Redpath et al., 2015). Such interactions can occur wherever humans and wildlife live alongside each other, with the competition for shared and limited resources often resulting in conflict (Conover, 2002). These conflicts are rooted in both social and ecological causes, where wildlife interactions that result in negative economic or social development can elicit human responses that negatively impact biodiversity conservation (Clark & Slocombe, 2011). In addition, conservation actions that increase global wildlife populations may lead to greater instances of conflict and thus jeopardize economic development of communities living alongside wildlife (Inskip & Zimmermann, 2009). The relationship between biodiversity conservation and economic development in the context of human-wildlife conflict demonstrates that these are complex socio-ecological systems.

Large carnivores are critical species to the conservation movement. They are ecologically identified as keystone species whose conservation benefits the broader ecosystem (Farashi & Shariati, 2018). In addition, their public adoration as charismatic megafauna fuels their protection around the world. However, conflict can arise between large carnivores and communities living within or near conservation areas. Livestock depredation is the most agreed upon driver of this conflict as pastoralism, a form of animal husbandry, is crucial to the livelihoods of many remote communities (Lute et al., 2018). The Nepal Himalayas is one such region with conservation areas home to both pastoralist communities and a charismatic megafauna: the snow leopard. The snow leopard is a keystone species of the Himalayas listed as vulnerable to extinction with a decreasing population (Mccarthy & Chapron, 2003; IUCN, 2017) and a diminishing habitat by climate change (Forrest et al., 2012). The most significant threat to snow leopard survival has been identified as retaliatory killings by local community members as a response to livestock depredation (Nowell, 2016), and this depredation has been extensively documented throughout Nepal (Bagchi & Mishra, 2006; Chetri et al., 2017; Chetri, Odden, Devineau, et al., 2019; Devkota et al., 2013; DNPWC, 2017; Ikeda, 2004; Oli et al., 1993). As the body of knowledge surrounding this conflict continues to grow, the question now turns to how to best foster coexistence.

Coexistence strategies for snow leopard-human conflict include proactive measures to reduce livestock depredation such as predator proof night corrals, and reactive measures to provide monetary relief to community members such as livestock insurance schemes. Stakeholders and conservation managers will need to increasingly plan for the adoption of these strategies with limited funding and resources. The challenge managers face is how to best allocate time, funding, and resources, for the greatest positive impact. For example, a predator proof night corral could save up to five snow leopards if placed effectively, as reduced depredation would result in the reduced need to retaliate (Jackson & Wangchuk, 2004). Alternatively, if a night corral is placed incorrectly in low suitability habitat of the snow leopard it would eliminate a crucial food source while providing no alternative prey species, threatening snow leopard survival (Bagchi, 2019). The need to understand the best implementation and impact of coexistence measures in the context of snow leopard-human conflict is mirrored in the larger human-wildlife conflict literature (Bommel, 2019; Frank, 2016; Miller et al., 2016; Rio-Maior et al., 2019).

1.2 Research Rationale

The complex relationship between humans and wildlife in these conflict scenarios highlights why it is crucial that coexistence is addressed from both a social and ecological perspective. Only coexistence that accounts for the needs of both humans and wildlife will be successful locally and hold the ability to meet international targets for biodiversity conservation and economic development. As a result, this thesis looks to understand both ecological and social dimensions of snow leopard-human conflict.

From an ecological perspective, a spatial understanding of conflict is critical to the implementation of conflict mitigation measures. Spatial predation risk modelling is an emerging low-cost tool that captures the spatial dynamics of past livestock depredation events to identify high-priority areas most at risk for future depredation (Miller, 2015). With an origin in ecology as a tool to investigate predator-prey relationships, spatial predation risk modelling has recently been applied to the context of other large carnivore-livestock interactions (Abade et al., 2014; Goljani Amirkhiz et al., 2018; Miller et al., 2015; Rostro-García et al., 2016; Zarco-González et al., 2012), but has not yet been applied to the context of the snow leopard. Additionally, many models did not validate results which is a crucial step in assessing a model's predictive abilities (Miller, 2015). A spatial understanding of high-risk areas of livestock depredation would allow stakeholders to prioritize conflict mitigation measures, such as predator proof night corrals, to the areas that such efforts would offer the most impact.

From a social perspective, the human dimensions of human-wildlife conflict are critical to fostering coexistence. While the reduction of physical manifestations of conflict such as crop loss or livestock depredation are often used as the indicator of successful coexistence (Bagchi & Mishra, 2006; van Eeden, Crowther, et al., 2018; van Eeden, Eklund, et al., 2018), there is also a need to reduce the perceived conflict felt by communities. There is a proven mismatch between how a local community perceives carnivore-human conflict and the actual level of conflict endured (Dickman, 2010). For example, intangible costs such as psychological, fear, and risk, have been demonstrated as far more significant when explaining attitudes towards wildlife involved in conflict than tangible costs such as number of livestock killed (Kansky et al., 2014). The field of attitude research is one way to investigate how local communities perceive wildlife in this context. A research gap remains in the understanding of local attitudes, as only a handful of studies to date have investigated local attitudes towards snow leopards in Nepal (Oli et al., 1994; Hanson et al., 2019; Khanal et al., 2020).

With both an ecological and social dimension to this conflict, the two can then be combined to outline potential pathways to the future of coexistence. A research approach that is able to provide insights into both biodiversity conservation and economic development to offer management implications for coexistence based on this broader understanding is more powerful than the investigation of one alone. This research can guide future management decisions on conflict resolution strategies that are able to meet the needs of both the communities and the snow leopard.

1.3 Research Objectives and Questions

The overarching theme of this research is human-snow leopard coexistence. I approach the term coexistence as a dynamic state where both humans and carnivores co-occur while maintaining a tolerable level of interactions, ensuring both a healthy wildlife population and social legitimacy for communities (Carter & Linnell, 2016). This definition of coexistence addresses the broader theme of sustainable development, where coexistence meets both the needs of biodiversity conservation and economic development. A deductive research strategy is applied to this thesis, collective quantitative data on both social and ecological dimensions of coexistence to determine the acceptance or rejection of each null hypotheses. Open ended questions during the questionnaire and qualitative notes gathered in the field are also used in support of findings from the quantitative analysis. In terms of research design, this thesis uses observational research, more specifically case study design, to test each research hypothesis. The communities living in the Dolpo district of Nepal, specifically within the boundaries of Shey Phoksundo National Park, offer an ideal case study to meet the primary aims of this research. This location will be justified in chapter 2 of this thesis.

The primary aim of this research is to investigate the social and ecological dimensions of snow leopard-human coexistence in Shey Phoksundo National Park to identify:

i) the spatial drivers of livestock depredation

ii) the determinants of local attitudes towards snow leopards.

The following research questions will be examined to meet primary aim i)

1. What are the attitudes of local communities towards the snow leopard?
2. What are the determinants of local communities' attitudes towards the snow leopard?

The following research questions will be examined to meet primary aim ii)

1. What are the spatial drivers of intensity of livestock depredation by snow leopards in Shey Phoksundo National Park?
2. Which areas have the highest relative risk of livestock depredation by snow leopards in Shey Phoksundo National Park?

1.4 Research Context

The following sections will now draw on a wider body of literature as it relates to snow leopard-human coexistence in Nepal. In its broadest form, this begins with a discussion on how to balance biodiversity conservation with economic development at a global scale. This section then explores the challenge of human-wildlife conflict around the world and the state of current research. Next, I focus on the unique context of large carnivore-human conflict and what makes these scenarios specifically challenging in and around protected areas. This will also highlight some current challenges and opportunities for human-carnivore coexistence. This research context section ends with a biological and ecological overview of the focal species in question: the snow leopard.

1.4.1 Balancing Biodiversity Conservation and Economic Development

The balance of biodiversity conservation and economic development is a crucial global undertaking. Global biodiversity indicators such as the IUCN Red List demonstrates that over a quarter (28%) of all assessed species on earth are threatened with extinction (IUCN, 2023). Economic development can be placed as the root of this crisis and labeled the antagonist in the name of biodiversity conservation. For example, overexploitation of natural resources, agricultural production, and urban development are highlighted as key global threats to biodiversity conservation fueled by economic development under an ever-increasing human population (Maxwell et al., 2016). Another historic example of humans as the antagonist is perhaps most apparent through the adoption of fortress conservation, a ‘solution’ that began in North America and spread across the world where humans are excluded entirely from natural areas in the name of conservation. With the belief that humans are the root cause of biodiversity loss, the total and complete exclusion of humans from natural areas appeared as the only solution to protect wild places. Examples range from Native Americas displaced from their traditional territories during the creation of Yosemite, to the Masai displaced from their homelands of the now called Serengeti (Dowie, 2009). However, this form of conservation can harm local communities by denying access to local resources (Tilman et al., 2017). Protected areas of this strict form of governance restricts resource use through legislation. In turn, these laws then place local communities who had historically accessed these natural resources now as criminals, with international spotlight critiquing how illegal poaching and resource extraction is harming global biodiversity conservation (Robbins et al., 2006). However, new global targets of the twenty first century have emphasized a major shift in biodiversity conservation. This outlook now places sustainable development as the core of both biodiversity conservation and economic development.

While some may still feel biodiversity conservation and economic development are at odds with one another, there are clear indicators of the shifting mindset towards a balance between the two in the twenty first century. The United Nations Sustainable Development Goals are perhaps the best indicator of this shifting mindset towards both environmental and human well-being. Three of these seventeen goals have a clear focus on biodiversity conservation: climate change, life on land, life below water (United Nations, 2015). Four of these goals have a clear focus on economic development: no poverty, decent work and economic growth, industry innovation and growth, and sustainable communities (United Nations, 2015). These goals have been adopted by many countries around the world as we work towards this balance. There are also growing fields in research and practice of resource management that explores this intersection of both biodiversity conservation and economic development. Community based natural resource management is a model of resource management that devolves governance to address social justice and community governance of local resources (Gruber, 2010). A case study in Ghana reveals that this form of resource management results in greater transparency and greater decision-making power of local communities in relation to their natural resources

(Murray et al., 2019). Another example of this integration is in the field of Integrated Conservation and Development Projects (ICDP). These ICDP's aspire to combine conservation goals with rural development. In reality such projects produce mixed results, such as the example of an ICDP enterprise-based conservation strategy in Brazil that found increased income of local communities following project implementation but no change in forest conservation (Bauch et al., 2014). The complex interactions between social and ecological systems may be more of a constraint to achieve sustainable development goals that the limits of natural resources themselves, and therefore management strategies that meet both economic and environmental needs are required (Tallis et al., 2018).

Addressing the complexities of these socio-ecological systems is of heightened importance in developing countries. Developing countries are known to host a majority of the world's biodiversity (Jenkins, 2003). These biodiversity hotspots are often in the spotlight of global biodiversity conservation while overlapping with rural areas where livelihoods of communities depend on natural resources, also known as poverty traps (Barrett et al., 2011). The immediate needs of economic development in these resource dependent communities then must be accounted for in biodiversity conservation initiatives (Tilman et al., 2017). This complexity can also be highlighted through a global lens that shows while biodiversity continues to decline globally, poverty continued to rise with 2022 seeing an increase in those living in extreme poverty (United Nations, 2022). To address these global challenges of biodiversity conservation and economic development, policy implementation and management strategies must address both in unison. Particularity in developing countries, policy that advances biodiversity conservation should not be done at the expense of these resource dependent communities (Palmer & di Falco, 2012). For stakeholders to make informed resource management decisions they rely increasingly on data that can addresses both the ecological and human dimensions of these complex socio-ecological systems to achieve true sustainable development (Cowling et al., 2004). With remote communities in developing countries striving to improve their livelihoods, a context specific understanding of these socio-ecological systems is needed to ensure biodiversity conservation can also meet the demands of local communities.

1.4.2 Global Human Wildlife Conflict

The nature of conflict between humans and wildlife encompasses a diversity of species and communities around the world. The most recent estimate of human-wildlife conflict amongst peer-reviewed literature found 262 unique species involved across 99 countries (Torres et al., 2018). Examples include North America's long and complicated history with wolves, to elephants raiding crop fields in Africa (Hoare, 2015), to tigers killing livestock in Asia (Inskip et al., 2013). Through drivers such as population growth, agricultural expansion, and climate change, these conflicts are only predicted to increase over time (Nyhus, 2016). This highlights that this complex conservation challenge needs to be addressed promptly. Amongst academic literature mammals are the most frequent order of species that engage in these interactions, with damage to crops the leading type of interaction followed by livestock depredation and attacks on humans (Torres et al., 2018). The impact of these conflicts and tolerance of community members towards these wildlife species varies based on the local context. A single species of wildlife can engage in a variety of negative interactions with humans, such as elephants in Mozambique reported to both attack humans and raid crops (Dunham et al., 2010). Interaction between humans and wildlife in a given location can also be predator specific. For example, on Vancouver Island both black bears and cougars are present. The most common interactions between humans and black bears reported to a local conservation hotline involved garbage or property damage, while cougar interactions involved livestock injury/death or attacks on pets (Klees van Bommel et al., 2020). With the diversity of interactions and wildlife involved in human-wildlife conflict, it should come as no surprise that the impact of biodiversity conservation of these wildlife species can result in varying impacts on the economic development of communities living alongside them.

A body of research has placed emphasis on the human dimensions of human-wildlife conflict (Bhatia et al., 2020; Clark et al., 2020; Dickman, 2010; Redpath et al., 2015). While many advocate for global biodiversity conservation of wildlife species involved in these conflicts, there is also a need to advocate for the livelihood needs of local communities involved. One pathway to identify the negative impacts on communities is through the quantification of damage to livelihoods caused by wildlife. For example, outside of Serengeti National Park households lost 5 livestock on average in 2003 to primarily hyena depredation, for a total economic loss of $12,846 USD (Holmerna et al., 2007). Another example in India demonstrates how 45% of households interviewed experienced crop damage from Asian elephants, quantifying impact by crop witch maize and millets both accounting for 20% of damage (Ramesh et al., 2022a). However, a quantitative assessment of financial impact alone is not enough to address the social dimensions of human wildlife conflict. Research that understands perceptions, tolerance, and attitudes of local communities is required to inform conflict management strategies. This is because the actual level of conflict measured through such quantitative indicators has proved often to mismatch with the level of perceived conflict felt by the communities involved (Dickman, 2010). For example, there are intangible costs that cannot be quantified such as psychological, fear, and risk, that have proved far more significant when explaining attitudes towards wildlife (Kansky et al., 2014). A specific example of this can be observed in studies that reveal local attitude towards large carnivores such as the snow leopard is not significantly influenced by the number of livestock lost to depredation (Hanson et al., 2019; Suryawanshi et al., 2014). This suggests the importance of underlying social drivers can outweigh the physical manifestation of conflict when examining local perceptions of large carnivores. Overall, the impact of human-wildlife conflict on communities must be identified and understood for successful management.

1.4.3 Human-Carnivore Conflict in Protected Areas

Of all the wildlife species, carnivores are often found at the forefront of human-wildlife conflicts. While carnivores are internationally regarded as charismatic megafauna and ecologically integral to ecosystem conservation (Farashi & Shariati, 2018), local communities who share space with these species fear safety for themselves, their communities, and their livelihoods (Atwood & Breck, 2012). As the human population expands farther into wildlife dominated landscapes, human-carnivore interactions are likely to increase (Carter & Linnell, 2016). As a result, carnivore conservation often comes with controversy as an opposition to economic development and human safety. One of the leading threats to carnivore populations around the world are human-wildlife conflicts, as negative interactions that threaten local livelihoods or personal safety and lead to retaliation against these carnivores (Inskip & Zimmermann, 2009). Successful management and effective conflict mitigation of human-carnivore conflict is one that must then address both ecological and social perspectives.

The top three most agreed upon drivers of human – carnivore conflict are livestock depredation, fear of carnivores, and mistrust of managers respectively (Lute et al., 2018). Additional drivers can include land ownership, resource restrictions, and education (Inskip et al., 2013; Webber & Hill, 2014). The diversity of communities, wildlife, and drivers can result in a variety of conflict scenarios unique to the local context they occur. These scenarios can result in retaliation and persecution of the problem carnivore species by local communities, or a hindrance of support for conservation initiatives (Littin et al., 2004). For example, while coyotes have very few instances attacking humans in North America, 66% of people surveyed in California and Illinois did not want to see coyotes in their neighborhood (Elliot et al., 2016). In a separate case study, Grizzly bears in Wyoming were responsible for an average of 58 calve deaths a year, fueling a resistance amongst ranchers to programs looking to recovery of grizzly bear populations (Sommers et al., 2010). These examples highlight the importance of fostering coexistence that benefits both local communities and carnivores.

There is a spatial relationship between protected areas and human-carnivore conflict. Carnivore conservation planning often includes protected area management to meet the large environmental needs of carnivores (Noss et al., 1996). However, in the name of biodiversity conservation local communities have been displaced from these areas, an action largely criticized for unfair treatment of these communities (Brockington & Igoe, 2006; Rangarajan et al., 2009). In addition, nothing prevents the increasing carnivore populations in these protected areas from roaming beyond the borders and interacting with humans. In fact, many carnivore conservation professionals agree that large carnivores most often co-occur with humans in a variety of mixed-use landscapes (Redpath et al., 2017). This is also demonstrated through the sentiment that conservation professionals hold that large carnivores and humans can share the same landscape (Lute et al., 2018). This history that entraps large carnivore conservation leads to the underlying need to identify human-human conflict in and near protected areas. Human-human conflict can arise between local communities who seek economic development and resource use, with those stakeholders who seek biodiversity conservation objectives and environmental protection (Peterson et al., 2010; Redpath et al., 2015). Protected areas today are increasingly confronted with sustainable development and must find a space for economic development alongside biodiversity conservation. Human-wildlife conflict is one aspect of protected area management that must be resolved in a way that addresses this balance.

1.4.4 Human-Carnivore Coexistence

Coexistence between humans and wildlife is a focal point of research in this field (Bhatia et al., 2020; Dorresteijn et al., 2016; Frank, 2016; Goswami et al., 2013; Lamb et al., 2020; Madden, 2004; Pooley et al., 2020). The importance of finding solutions that both address biodiversity conservation and community development needs lie at the heart of these conflict resolution strategies. For the purposes of this thesis, I approach the term coexistence as a dynamic state where both humans and wildlife co-occur while maintaining a tolerable level of interactions, ensuring both a healthy wildlife population and social legitimacy for communities (Carter & Linnell, 2016). Coexistence is therefore complex by design as it requires resolutions that meet both ecological and social needs simultaneously.

This complexity leads to many research gaps in the field of carnivore-human coexistence. Firstly, there is a lack of understanding of context specific social and ecological conflict drivers (Dickman, 2010). To resolve these conflicts stakeholders must first be able to identify the roots of conflict from a biodiversity conservation and economic development perspective. Recent tools have emerged to understand these drivers that should be further examined at a local context. For example, ecological drivers of human-carnivore conflict can be examined through hot spot mapping to identify environmental variables that best identify areas of high conflict risk (Miller, 2015). A similar technique that addresses social drivers of risk perception includes participatory risk mapping, which highlights the relative importance of risks felt by communities, the relative frequency of those risks, and where on the landscape they take place (Smith et al., 2000). Secondly, there is a lack of social science research in the field of carnivore-human coexistence. Growing evidence reveals that social factors are largely excluded from conflict studies despite proving greater importance in driving conflict than physical damage (Dickman, 2010). For example, mixed-method studies that employ social and ecological methods are rare in case studies involving *Panthera* cat species (Holland et al., 2018). An understanding of human dimensions can also identify where drivers of conflict are underlying human-human conflicts between local communities and those with conservation objectives (Redpath et al., 2015). Thirdly, there is a lack of understanding on the effectiveness of conflict mitigation strategies. Research is now calling for the evaluation of site-specific mitigation interventions that account for local social and ecological contexts (Eklund et al., 2017; Inskip et al., 2013; Inskip & Zimmermann, 2009; van Eeden, Crowther, et al., 2018). For example, mitigation strategies have demonstrated a variable effectiveness based on local context to reduce livestock depredation (Miller et al., 2016). This raises the challenge that if effective mitigation is site specific, a vast amount of research is required across species, location, and cultural contexts. To date, much of the empirical evidence for mitigation strategies is from North America, followed by Europe, then Africa (Miller et al., 2016). These research gaps highlight the opportunities in this field to examine coexistence that meets the needs of both carnivores and communities.

1.4.5 Focal Carnivore Species: The Snow Leopard

The snow leopard is a unique species recognized by the Latin name *Panthera uncia*. It falls under the genus of *Panthera* along with other large cat species such as the tiger, lion, jaguar, and leopard. The closest relative to the snow leopard within this genus, forming a sister relationship, is the tiger (Tseng, 2014). The divergence of the snow leopard and tiger species from other *Panthera sp*. is thought to have occurred between 4.86 and 15.13 million years ago (Tseng, 2014). The subfamily of *pantherines* is thought to have originated in Asia, with the oldest known fossil discovered in the Himalayan Range dating between 8.37 – 27.68 million years old (Tseng, 2014). Broadly, the snow leopard is one of thirty-eight cat species found in the family *Felidae*, many of which are threatened or endangered under the IUCN red list and

CITES (Davis, 2010). The snow Leopard is listed as vulnerable to extinction under the IUCN Redlist (McCarthy et al., 2017).

Of all the big cats found in the genus *Panthera*, the snow leopard has the smallest body length of 1 to 1.3 m, and a weight of 20-50 kg (Kitchner et al., 2016). The snow leopard is primarily grey with dark brown or black rosettes along its body and tail, and a lighter white tint on the underside of the body (Hemmer, 1972). A variety of adaptations are present on the snow leopard that allows it to be the apex predator of high elevation mountainous ecosystems. Firstly, the snow leopard has a large nasal cavity that is likely an adaptation to the cold environment as it allows for air to warm when breathing (Hemmer, 1972). Secondly, the snow leopard has the weakest average bite force of the *Panthera* species, which corresponds to its relatively small size and small size of its prey species that live in the alpine ecosystem (Christiansen, 2007). When compared to bite force of other cats with similar body mass such as *Puma concolor,* the bite force of the snow leopard is weaker, at 363.0 compared to the puma at 499.6 (Christiansen, 2007). Lastly, the tail of the snow leopard is adapted to both the rough and cold environment. The mean length of a snow leopard's tail is 83% of its head and body length, which acts as both an insulator when resting and a balancing tool when navigating rough terrain in pursuit of prey (Kitchener et al., 2016).

The snow leopard is distributed in the high mountainous regions of twelve countries in Asia: Afghanistan, Bhutan, China, India, Kazakhstan, Kyrgyzstan, Mongolia, Nepal, Pakistan, Russia, Tajikistan, and Uzbekistan (McCarthy and Chapron, 2003). The home range size of snow leopards has been shown to vary across this range as a result of varying methods of data collection employed. In optimum snow leopard habitat in Nepal, the home range of five snow leopards was observed to be between 12 km^2 and 39^2 (Jackson and Ahlborn, 1989). In less desirable habitat, such as Mongolia, the home range of a single leopard can exceed 400 km^2 as they must travel farther in search of prey (McCarthy and Chapron, 2003). Prey species of the snow leopard are diverse for this opportunistic predator and include both wild prey and domestic livestock. Scat analysis have revealed wild prey species in Nepal such as blue sheep, Himalayan marmot, Royle pika, Royle vole, weasel, stone marten, birds, red fox; and domestic livestock such as yak, horse, ox, goat, and sheep (Oli et al., 1993). Of these prey species, the blue sheep was the most frequently recorded prey species in 51% of scat followed by marmot found within 21% of scat (Oli et al., 1993). Recent studies have agreed with the importance of both blue sheep and marmot is the diet of snow leopards and suggested that the marmot acts as a buffer species as it is more numerous throughout snow leopard habitat (Devkota et al., 2013). In addition, they add that plant species may also play a role in the diet of snow leopards, as a recorded scat was shown to contain only plant species (Devkota et al., 2013).

Population estimates are a challenge for a species as elusive as the snow leopard. The Snow Leopard Conservation Action Plan for Nepal (2017-2021) places the total snow leopard population between 3,921 – 6,290 individuals (SLCAP, 2017). Alternative population estimates include 4,080 – 6,500 (McCarthy and Chapron, 2003), 4,500 – 7,500 (Jackson et al., 2010). As new technology is applied to the snow leopard population estimates such as camera trapping, radio collars, and geographic information systems, the population estimates continue to shift. In a recent study, a concern was raised that of the twelve countries included in the range of the snow leopard, only six have peer-reviewed population density estimates (Suryawanshi et al., 2019). The author questions the accuracy of existing population studies as the data collected in the field covers only 0.3% – 0.9% of the snow leopard range (Suryawanshi et al., 2019). In addition, sites that researchers choose to monitor snow leopard populations were often biased towards good quality habitat which could lead to an overestimation of the population (Suryawanshi et al., 2019). These concerns were demonstrated through another recent study in Nepal that found a snow leopard density of 0.95 individuals per 100 km^2 (Chetri, Odden, Sharma, et al., 2019). This is lower than previous estimates in Nepal, likely due to the large study size that was used in this recent publication not solely in prime snow leopard habitat (Chetri, Odden, Sharma, et al., 2019). The authors also found that densities varied by elevation and topography, ranging from 0.1 to 1.9 snow leopards per 100 km^2 (Chetri, Odden, Sharma, et al., 2019), reaffirming the concerns of others that the current snow leopard population estimates may be overestimating the true population. Future research will need to refine population estimates. A robust population estimate is of particular importance as the snow leopard was recently reclassified from “endangered” to “vulnerable” by the IUCN Red list (McCarthy et al., 2017) when new population estimates placed the total snow leopard population higher than previously thought.

1.5 Thesis Outline

The second chapter of this thesis outlines the study site of Shey Phoksundo National Park. This begins through and introduction on the history of protected areas in Nepal. It then presents a status on the current state and historic state of and snow-leopard human conflict in Nepal. This chapter concludes with the justification of the study location of Shey Phoksundo National Park.

The third chapter of this thesis examines the ecological dimensions of snow leopard-human coexistence. Ecological dimensions will be refined for the purpose of this thesis to the spatial dynamics of livestock depredation by snow leopards. While mitigation efforts have been proposed to foster coexistence such as night corrals or alternative livestock grazing pastures (Bagchi & Mishra, 2006; Jamtsho & Katel, 2019), the spatial dynamics of snow leopard livestock conflict are unknown. Understanding these dynamics are crucial for effective implementation of mitigation strategies. Predation risk modelling is an emerging low-cost tool to spatially predict the areas that are most susceptible to future livestock depredation, allowing managers to identify priority areas for targeted mitigation efforts (Miller, 2015). Originating as a tool for ecologists to investigate predator-prey relationships, predation risk modeling has recently been applied to a few case studies of large carnivore-livestock interactions (Abade et al., 2014; Miller et al., 2015; Rostro-García et al., 2016), but not yet to snow leopards.

The fourth chapter of this thesis examines the social dimensions of snow leopard-human coexistence. Social dimensions of coexistence will be narrowed for the purpose of this thesis to the investigation of local attitudes of snow leopards and drivers of those attitudes. It is well known that local communities play a crucial role in conservation success, and retaliatory killings of the snow leopard have been emphasized as a significant threat to snow leopard survival (Nowell et al., 2016). Few studies have focused on attitudinal research in this context. The identification of attitude drivers could allow for targeted mitigation strategies that address the perceived conflict felt by community members. I used a survey methodology with the specific method of a questionnaire to gather quantitative data. Questionnaires were designed to collect information on herder attitudes towards snow leopards and the potential variables that could influence attitudes. Weighted composite attitude scores was used to identify local attitudes towards snow leopards as the dependent variable. These attitude scores were then examined using the multiple linear regression to investigate drivers.

The fifth chapter of this thesis turns towards coexistence. It highlights the current state of conflict resolution efforts in place at the time of data collection in our study site. These efforts include predator proof night corrals and government relief schemes for wildlife damage. Qualitative notes that were recorded during surveys are used to provide a snapshot of community perceptions towards these strategies. This chapter then shifts its focus to the future of conflict resolution. Supported by the analysis of chapters 3 and 4 as well as qualitative notes, this section offers management implications that can improve these conflict resolution efforts. This includes both adaptations and expansion of current strategies and suggests alternative conflict resolution strategies that could be successful in the region that would meet both the needs of biodiversity conservation and economic development.

The sixth and final chapter of this thesis will offer a synthesis and conclusions to the research. This will include a discussion of the strength and limitations of this research, future recommendations, and next steps for additional research in this field.

Chapter 2: Study Site

2.1 Nepal: Biodiversity Conservation and Economic Development

Nepal is a land locked country in Southern Asia bordering India to the west, south, and east, and Tibet to the North. The country runs along the Himalaya Mountain Range and is composed of five distinct physio geographical regions of increasing elevation: Terai Plain, Siwalik Hills, Middle Mountain, High Mountain, and High Himalaya (Shrestha & Aryal, 2011). Within the High Himalaya range, Nepal contains eight of the world's ten highest peaks reaching a height of over 8,800 meters (Paudel et al., 2012). Precipitation patterns vary across the country, ranging from humid in the east and dry in the west (Paudel et al., 2012). As a result of both the altitudinal and precipitation variation across the country, a diversity of life is found in Nepal. From populations of elephant and rhinoceros in the lowlands to snow leopards and lammergeyers in the mountain alpine. Nepal boasts 118 different ecosystems hosting 8.9% of the world's bird population, 3.9% of the world's mammal population, and 6% of the world's bryophytes, all impressive numbers for a country whose land mass is only 0.1% of the world's total (Paudel et al., 2012). Many of these charismatic megafaunas found in Nepal are also threatened for extinction such as the red panda, Bengal tiger, one-horned rhinoceros, and snow leopard (IUCN, 2022). These flagship species have been identified in global conservation organizations such as World Wildlife Fund as focal species for biodiversity conservation (WWF Nepal, n.d).

Over the past fifty years Nepal has experienced vast economic policy changes from modernization to state monopoly to free market approaches, however it has also witnessed an increase in income inequality with an increase in poverty in rural areas where the majority of the population lives (Devkota, 2007). The current population estimate for Nepal is slightly over 28 million people (World Bank, 2018). There is a variety of languages and religions practiced throughout the country by 125 caste/ethnic groups, the most populous being Chhetri at 16.6% followed by Brahmin at 12.2% and Maga at 7.1% (Central Bureau of Statistics Nepal, 2012). The caste system stratifies social groups in a hierarchical structure that challenges how individuals can acquire land, education, and government positions (Baumann et al., 2019). In terms of livelihoods, the people of Nepal rely heavily on agriculture and tourism. Agriculture is relied upon by 80% of the population for their livelihood (Shrestha & Aryal, 2011) and tourism employed approximately 500,000 people in Nepal in 2015 accounting for 4% of the country's GDP (Beirman et al., 2018). Internationally, the country is recognized for its natural beauty and diverse cultures which attracted 780,000 tourists to Nepal in 2015 (Beirman et al., 2018). Many of these tourists made their way to perhaps the best-known landscape feature in Nepal: Mount Everest base camp. This region saw 45,000 tourists alone in 2016 (Beirman et al., 2018). The reliance on agriculture and tourism for the livelihoods of so many in Nepal is undeniably linked to protected areas and their management.

Up until the 1950's Nepal was governed by a monarch in the Rana dynasty, a governance structure which had no rules and regulations on the use of natural resources (Bhattarai et al., 2017). The first protected area establishment in Nepal was in 1973: Chitwan National Park. Legislation based on the North American national park model came along with this establishment including the 1973 National Parks and Wildlife Conservation Act and the creation of the Department of National Parks and Wildlife Conservation (DNPWC) with strict resource management laws (Heinen & Kattel, 1992). These laws were created to conserve species such as the one-horned rhinoceros and Bengal tiger in Chitwan now under threat from a period of rapid human re-settlement from the mid mountains to the lowlands fueled by a food crisis and novel malaria eradication initiatives (Bhattarai et al., 2017). This early form of protected area management leaned heavily into biodiversity conservation and excluded economic development. For example, the establishment of Lake Rara National Park resulted in the removal of local communities who were forced to relocate from their villages in the mountains to the lowlands (Kharel, 1997). This is just one example that has led to a parks-people conflict in Nepal as communities advocate for their livelihood needs against conservation managers set on preserving biodiversity. Today, Nepal has thirty-three protected areas that cover roughly 23% of the country which include 12 national parks, 6 conservation areas, 13 buffer zones, 1 wildlife reserve, and 1 hunting reserve (DNPWC, 2022). There is now a greater emphasis on the need for protected areas to balance between biodiversity conservation and economic development. A shift has been observed from a strict no use governance structure to a more participatory and democratic plan for resource use by local communities (Bhattarai et al., 2017). However, this shifting nature of protected area management is not without challenges. As the pendulum continues to swing back towards a balance, perhaps the greatest challenge will be how to create coexistence between these biodiversity and economic development goals in protected areas in Nepal. At the forefront of this challenge is human-wildlife conflict.

2.2 Snow Leopard-Human Conflict in Nepal

A documented conflict exists in Nepal between remote herding communities and snow leopards (Aryal, Brunton, Ji, Barraclough, et al., 2014; Chetri, Odden, Devineau, et al., 2019; Chetri, Odden, Sharma, et al., 2019; B. Devkota et al., 2013; Ikeda, 2004; Oli et al., 1994; Schutgens et al., 2019; A. Shrestha et al., 2019; Wegge et al., 2012). The snow leopard is a keystone species of the Himalayas listed as vulnerable to extinction with a decreasing population and a diminishing habitat in the face of climate change (Forrest et al., 2012). One of the most productive land uses in these remote alpine regions is pastoralism; a nomadic form of livestock rearing practiced in ¾ of the world's countries by an estimated 200 – 500 million people (Mbow et al., 2019). Livestock depredation is the most agreed upon driver of large carnivore-human conflict (Lute et al., 2018), and has been well documented in Nepal (Chetri et al., 2019; Devkota et al., 2013; Kusi et al., 2020; Shrestha et al., 2012; Wegge et al., 2012). Most research in this field has focused on the quantification of livestock depredation. This research applies methods such as household surveys to determine number of livestock killed, or the analysis of snow leopard scat to reveal livestock remains.

Relatively few studies have examined perceived conflict. For the purposes of this thesis, I approach perceived conflict as the nonphysical manifestations of conflict felt by community members such as fear, tolerance, attitudes, and perceptions. Attitudinal research is one method applied by a handful of studies in Nepal (Hanson et al., 2019; Kusi et al., 2020; Oli et al., 1994). Two studies took place in Annapurna conservation area and one study took a comparative approach across multiple regions. The earlier research in Annapurna found only 4% of respondents holding a positive view of snow leopards while 93% held a negative view (Oli et al., 1994). The later research in Annapurna revealed a shift in attitudes as approximately 60% of respondents held a positive view of snow leopards while 20% held a negative view (Hanson et al., 2019). The increase in positive attitudes held by community members could suggest that communities in the Annapurna conservation area are growing more tolerant of snow leopards. This in turn could be a result of the positive impact of the conservation initiatives undertaken over that time period in the Annapurna conservation area. The most recent comparative study in upper Humla, upper Dolpo, and Kanchenjunga revealed that across all regions, 88% of respondents thought snow leopards were a problematic carnivore (Kusi et al., 2020).

Coexistence between snow leopards and remote herding communities in Nepal will require mitigation strategies targeted at reducing both actual and perceived conflict. A variety of mitigation strategies have been proposed to reduce this conflict in Nepal and more broadly throughout the snow leopard range (Appendix A). Predator proof night corrals and alternative husbandry practices aim to reduce the levels of livestock depredation (Jackson & Wangchuk, 2004). Livestock insurance schemes and the diversification of livelihood strategies to sectors such as ecotourism address the economic impact that results from livestock depredation (Maheshwari & Sathyakumar, 2019; Mishra et al., 2003a). Rangeland management practices and the creation of native ungulate only pastures aim to increase the abundance of native prey species, though these pastures could mimic the highly criticizes fortress conservation narrative

(Mishra et al., 2003; Shrestha et al., 2012). Lastly, education and awareness initiatives on snow leopards and their conservation could target perceived conflict felt by community members (Hanson et al., 2019). While coexistence strategies are offered in many papers on snow leopard – human conflict, little research has examined their effectiveness.

2.3 Case Study: Shey Phoksundo National Park

Shey Phoksundo National Park (SPNP) is a remote protected area in Dolpo district of Nepal (Figure 2.1). This protected area is the largest in Nepal spanning 3555 km^2 with an additional 1350 km^2 in the surrounding buffer zone (DNPWC, 2017). There are two main divisions to this region with differing geographic conditions: lower Dolpo and upper Dolpo. Lower Dolpo receives 1500 mm of rain annually and supports a mixed broadleaf and coniferous forest, while upper Dolpo lies in the rain shadow of Tibet and only sees 500 mm of rain annually (Khanal et al., 2020). A rich amount of biodiversity exists in Dolpo, including 32 mammal species and nearly 200 bird species (Kusi et al., 2018). Many of these species are vulnerable to extinction such as the snow leopard, wolf, black bear, and musk deer (B. Devkota et al., 2013).

This protected area is unique for a variety of reasons that make it the ideal case study for the study of snow leopard-human coexistence. Firstly, unlike other national parks in the country, communities living within the new park boundaries were not displaced at park formation. The main sources of income for these communities include livestock husbandry, agriculture, and non-timber for product collection (Kusi et al., 2020). Lower Dolpo is home to 550 people spread across 4 villages who have reduced their small livestock holdings due to an increase in tourism, but still rear large livestock such as yaks and horses (Khanal et al., 2020). In upper Dolpo there are over 2,500 inhabitants with less tourism opportunities and an average livestock holding of 40-per household animals consisting of both small livestock and large livestock (Khanal et al., 2020). Secondly, the region is thought to be home to the highest densities of snow leopards in the country. One study used a non-invasive genetic sampling of snow leopard scat and identified four different individuals of snow leopards in SPNP (Karmacharya et al., 2011). A separate study found the density of snow leopards in lower Dolpo at 1.2 individuals per 100 km^2, with upper Dolpo at 2.5 snow leopards per 100 km^2 (Khanal et al., 2020). An additional study suggested that this region is home to the highest density of snow leopards in the country at 3.2 individuals per 100 km^2 (DNPWC, 2017). The variation in snow leopard density reports for this region mirror the rest of Asia due to the elusive nature of this predator, the remoteness of its habitat, and the data collection technique employed. Despite a variation in density, there is no debate as to the importance of this region to snow leopard habitat. Of the total protected area size, 90% is classified as potential snow leopard habitat (DNPWC, 2017). Lastly, the overlap of local communities and snow leopards has resulted in conflict. Conflict can physically manifest in the form of livestock depredation. One study investigated diet of snow leopards in SPNP and revealed depredation in the region with an annual loss of 1.6 animals per household (B. Devkota et al., 2013). A more recent study suggests high levels of depredation, with just over 3% of total livestock holdings lost to snow leopard depredation in a single calendar year in lower Dolpo, and 10% in upper Dolpo (Khanal et al., 2020). Conflict can also result in negative perceptions, tolerance, and attitudes towards snow leopards. A single study investigated attitudes towards snow leopards in this region but did not make any conclusions beyond descriptive statistics (Kusi et al., 2020). The attitudinal and drivers of perceived conflict are left largely unknown. In conclusion, the combination of carnivore, community, and conflict make SPNP an ideal case study for this proposed research.

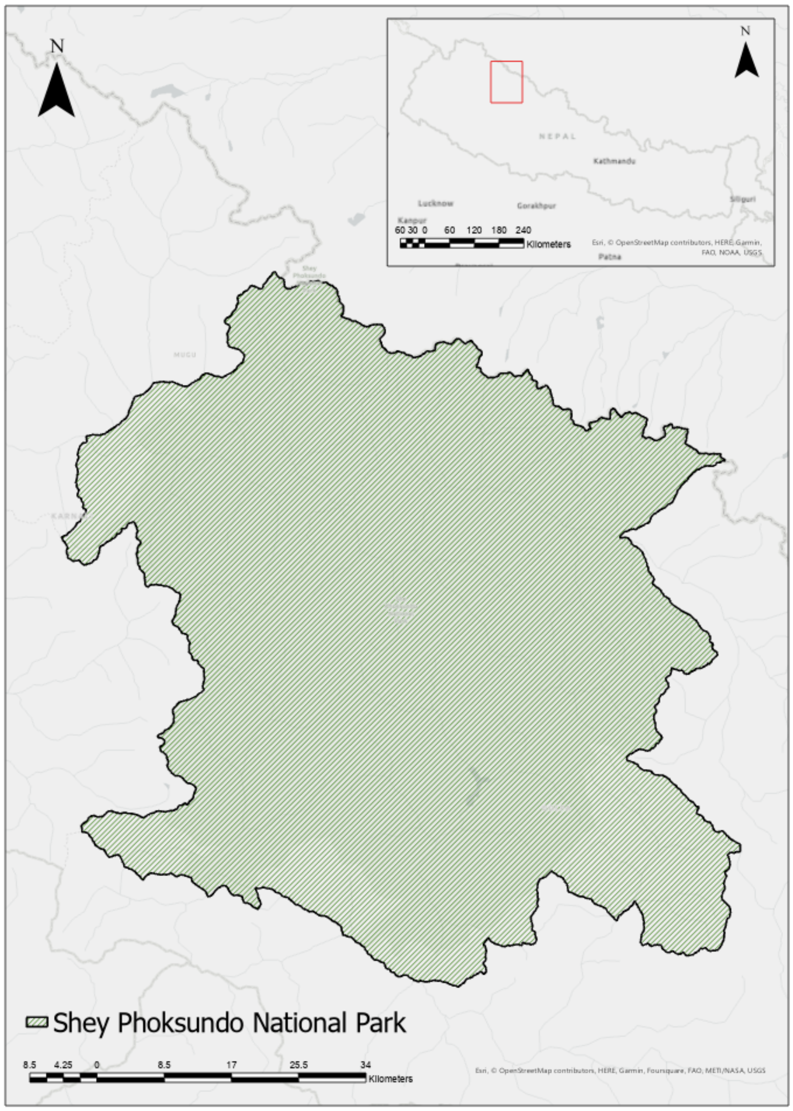

Figure 2.1: The location of Shey Phoksundo National Park is in relation to the rest of Nepal

Chapter 3: Ecological Drivers of Livestock Depredation: Conflict Hot Spots

3.1 Introduction

To meet global biodiversity conservation targets, human-wildlife coexistence will need strategies that help preserve wildlife species in conflict with humans. This chapter applies an ecological lens to identify the hotspots of livestock depredation by snow leopards in SPNP. In addition, it uncovers the environmental drivers of this depredation grounded in snow leopard biology and ecology. To date, many coexistence strategies have been offered that could help reduce conflict and in turn conserve snow leopards such as predator proof night corrals or livestock free grazing pastures (Bagchi & Mishra, 2006; Jamtsho & Katel, 2019). However, the spatial dynamics of livestock depredation by snow leopards across its range are largely unknown. These depredation hotspots and spatial drivers can help stakeholders prioritize where conflict resolution strategies are implemented to target high-risk areas. Predation risk modelling is an emerging technique to identify where on the landscape livestock are most susceptible to depredation and has been applied to other large carnivores such as tigers, lions, and common leopard (Abade et al., 2014; Miller et al., 2015; Rostro-García et al., 2016), but has not yet been applied to the context of livestock depredation by snow leopards.

3.1.1 Spatial Dimensions of Human-Wildlife Conflict

The introduction of geographic information systems (GIS) and remote sensing technologies broadened the field of ecology. While traditional ecology focused on local species dynamics, the availability of accurate spatial data shifted the focus to landscape level meta-population management, through links between local sites and populations at broad scales (Lachowski et al., 1994). A common present-day application of these GIS technologies in ecology is to species distribution modelling. Species distribution modelling is an umbrella term shading a host of modelling approaches and research applications. This form of modelling aims to predict the relative probability of occurrence of a given species through the combination of known occurrence data with environmental covaries that influence occurrence (Elith & Lethwick, 2009). Predicting the future range of at-risk species under various scenarios of climate change, investigating the viability of tropic rewilding projects, and predicting the spread of invasive alien plants are just some of the many applications (Forrest et al., 2012; Jarvie & Svenning, 2018; Smolik et al., 2010). One branch of species distribution modelling that has emerged in recent years is spatial Predation Risk Modelling (PRM). This application addresses the challenge of livestock depredation by large carnivores, which is the most agreed upon driver of carnivore-human conflict around the globe (Lute et al., 2018). PRM mirrors species distribution modelling, as it investigates the relative risk of livestock depredation through the combination of depredation records and features that influence depredation (Miller, 2015).

3.1.2 Livestock Availability and Accessibility to Large Carnivores

The high-risk areas of livestock depredation are the areas that livestock are most accessible to large carnivores. Livestock availability differs from livestock accessibility, and a distinction should be made between the two and models should look to incorporate these predator-prey interactions along with species abundance (Trainor & Schmitz, 2014). The occurrence and abundance of prey on the landscape (availability) does not mean a carnivore will be successful in its hunt (accessibility) (Miller et al., 2015). Broadly, large carnivores select which habitat to use on a landscape through a balance of many factors that include locating prey, conserving energy expenditure, and avoiding potential risks such as humans (Nisi et al., 2022). This habitat preference can lead to differing prey selection for large carnivores that coexist in the same landscape, such as in Nepal where the snow leopard prefers hunting cliff-dwelling ungulates whereas the Tibetan wolf hunting prefers plain dwelling ungulates (Chetri et al., 2017). At a finer scale, when deciding where to hunt, large carnivores often prioritize prey catchability (accessibility) rather than prey abundance (availability). For example, leopards have demonstrated a preference for prey catchability in areas with a mid-range of vegetation cover suitable for stalking, over areas with more prey abundance (Balme et al., 2007). Lions in Zimbabwe prefer to kill prey in areas with more dense thicket where prey catchability is likely higher than other vegetation covers (Davidson et al., 2012). While little research investigates the hunting strategy and success of the snow leopard due to its elusive nature, it is widely accepted that the snow leopard is an ambush predator that relies on ambush hunting (Mccarthy & Chapron, 2003). For a carnivore that relies on stalking as a hunting tactic, the ability to maintain hidden under cover increases the chance of hunting success (Yachi, 2000). Sites where a given carnivore has successfully killed livestock reveal the high-risk areas of prey accessibility, and thus predation risk. A spatial understanding of the areas of high livestock accessibility to snow leopards can help target management strategies to these regions of high vulnerability.

The relationship between livestock and wild ungulates in the high mountains is complex and often produces variable and context specific results. While wild ungulate density has demonstrated to influence snow leopard habitat suitability (M. Wolf & Ale, 2009), how that then in turn influences livestock depredation is complex and inconclusive. For example, in the mountains the Manag District of Nepal through a combination of rotational grazing and heterogeneity of forage plants, low stocking densities of goats and sheep offer coexistence with wild ungulates but they compete at high stocking densities (R. Shrestha & Wegge, 2008). Larger livestock such as yak were observed to compete more with wild ungulates as their range and diet overlapped more often, particularly in winter (R. Shrestha & Wegge, 2008). A study in Annapurna and Manaslu Conservation Areas found livestock depredation by snow leopards was highest in areas of high livestock and high wild ungulate densities, and lowest in areas of high ungulate prey and low livestock densities (Chetri et al., 2017). The appearance of high wild ungulate densities in both the lowest and highest depredation risk areas indicate the complex relationship between the snow leopard, wild ungulate, and livestock.

For the purposes of this thesis, the data on livestock and wild prey abundance does not exist for SPNP at a small enough scale to be included meaningfully into the modelling process. Therefor a decision was made moving forward to focus on livestock vulnerability (accessibility). This assumes that livestock are available through the study extent and this thesis will focus then on the landscape features that influence their vulnerability to depredation. The informed assumption of livestock availability will be justified in the study area section of this thesis but has been done my similar PRM studies (Miller et al., 2015).

3.1.3 Study Objectives

Conflict between pastoralists and snow leopards is known throughout Nepal (Aryal, Brunton, Ji, Barraclough, et al., 2014; Chetri, Odden, Devineau, et al., 2019; B. Devkota et al., 2013). Past research has largely looked to quantify this conflict in terms of number of livestock lost and the economic impact on communities (Ikeda, 2004). In addition, the retaliatory killing of snow leopards by communities following livestock depredation has been recorded, though exact numbers are unknown (Oli et al., 1994). Mitigation efforts have been proposed to reduce this conflict which include predator proof night corrals to protect livestock, insurance schemes to compensate herders, and livestock free grazing zones to increase wild prey abundance (Bagchi, 2019; Bagchi & Mishra, 2006). However, a spatial understanding of livestock accessibility to snow leopards, and therefor depredation risk, is unknown. This research gap will be addressed in the following two research questions:

I. What are the spatial drivers of intensity of livestock depredation by snow leopards in Shey Phoksundo National Park?

II. Which areas have the highest relative risk of livestock depredation by snow leopards in Shey Phoksundo National Park?

A spatial understanding of snow leopard-human conflict would benefit mitigation strategies. Firstly, livestock depredation rates have demonstrated to vary across the country (Chetri, Odden, Devineau, et al., 2019), suggesting that there could be spatial factors which lead to greater livestock depredation. Secondly, the knowledge of which spatial factors hold a greater influence on depredation provides the opportunity to target mitigation techniques to the most influential factors. Lastly, the spatial extent of this conflict is vast. Pastoralists do not have set ranches and instead graze their herds across large distances, and the home range of the snow leopard can fall anywhere between 12 km^2 to 1600 km^2 (Jackson & Ahlborn, 1989; McCarthy et al., 2005). This suggest mitigation techniques could be the most effective if targeted to areas on the landscape that have the highest relative risk of livestock depredation. This research aims to use a local hot spot analysis to determine clustering of livestock depredation points, and maxent modelling to identify any potential drivers of livestock vulnerability on the landscape.

3.2 Methods

3.2.1 Study Area

The study area for this research is Shey Phoksundo National Park (Figure 3.1). SPNP is a remote protected area in western Nepal comprised of a combined core zone and buffer zone spanning a total of 4905 km^2 (DNPWC, 2017).

However, the study area needs to be further reduced to answer our research questions. This is because the spatial extent for any form of species distribution modelling should most often reflect the goals of the study (Elith & Lethwick, 2009). For the purpose of Maxent, the spatial extent is the region that background points are sampled from and where the relative depredation risk will be predicted across. The larger spatial extent of the study, the more likely the model will draw background points from geographical conditions very different from the environmental conditions surrounding occurrence records, resulting in less informative background points (Barbet-Massin et al., 2012). In practice, this can result in models that appear better performing than they are. For example, one study proved that including river catchments not available to their target species inflated model performance, as the model was able to classify those areas as “low suitability” (Schmidt et al., 2020). In the context of this research, the spatial extent of our study was reduced to three village clusters where our surveys were randomly conducted: Phoksundo, Dho Tarap, and Saldang (Figure 3.1).

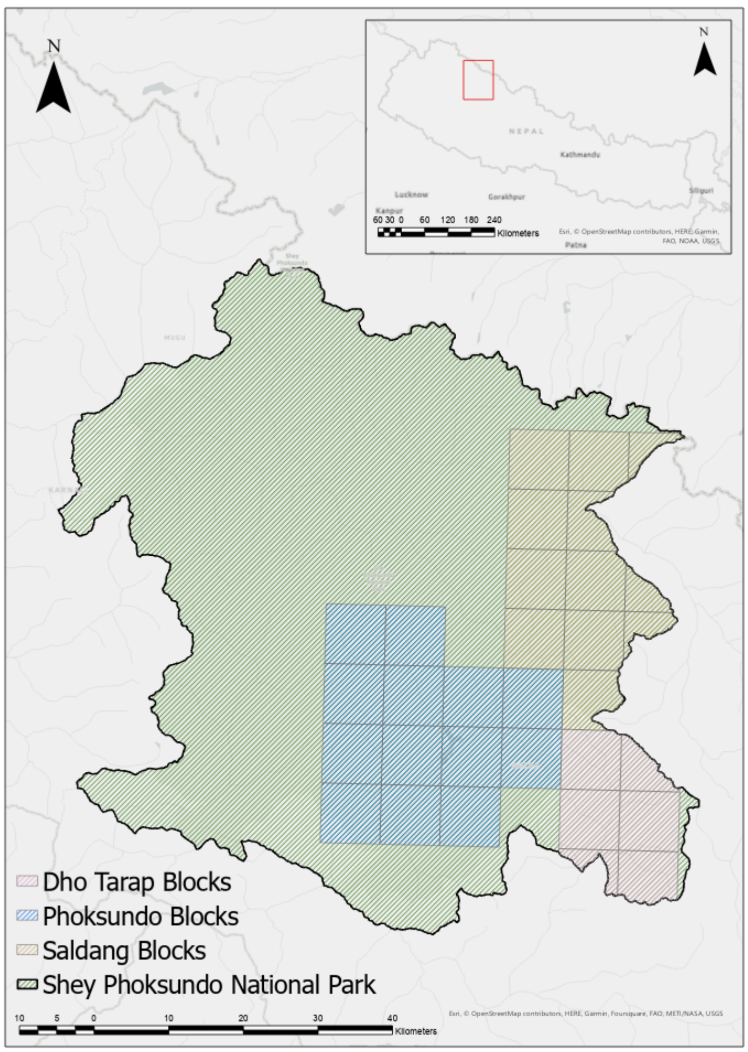

Figure 3.1: The spatial extent of this study in relation to the entirety of SPNP and Nepal.

These three village clusters are in the eastern region of SPNP and total 1737 km^2. It is understood that to make informative and realistic models, the spatial extent where the background points will be selected from should be the area that has been accessible to the species over the time period in question (Barve et al., 2011). In practice, this means that the spatial extent of our study needs to be the areas that are available to both snow leopards and livestock (therefor livestock depredation) over the 5 years of our study that depredation events were recorded. Our study extent was then examined to determine that this criterion was met for both snow leopards and livestock.

An informed assumption was made that livestock are available throughout the study extent. In the high mountain regions of Nepal, livestock are treated as a private commodity while pastureland to graze their livestock is treated as a public or common property (Gentle & Thwaites, 2016). Herders in these regions practice transhumance, the seasonal movement of livestock close to villages in the winter and high mountain pastureland by the summer (Tiwari et al., 2020) The seasonal transhumance of herders guiding their livestock throughout the pastureland can commonly take livestock multiple days walk away from the herder's home village (Gentle & Thwaites, 2016). In the neighboring region of Mustang, a study determined that distance to pasture area from village during summer and autumn was often a minimum of 6 km, even surpassing 18 km, as livestock are grazed in more distant and roam high mountain pastures (Aryal, Brunton, Ji, Barraclough, et al., 2014). To determine where livestock could be available in our study extent, I created a conservative buffer of 12 km from each village representing the areas that livestock could theoretically roam (figure 3.3) This buffer proved to cover the entirety of our study extent, leading to the assumption that domestic livestock could be available across the spatial extent.

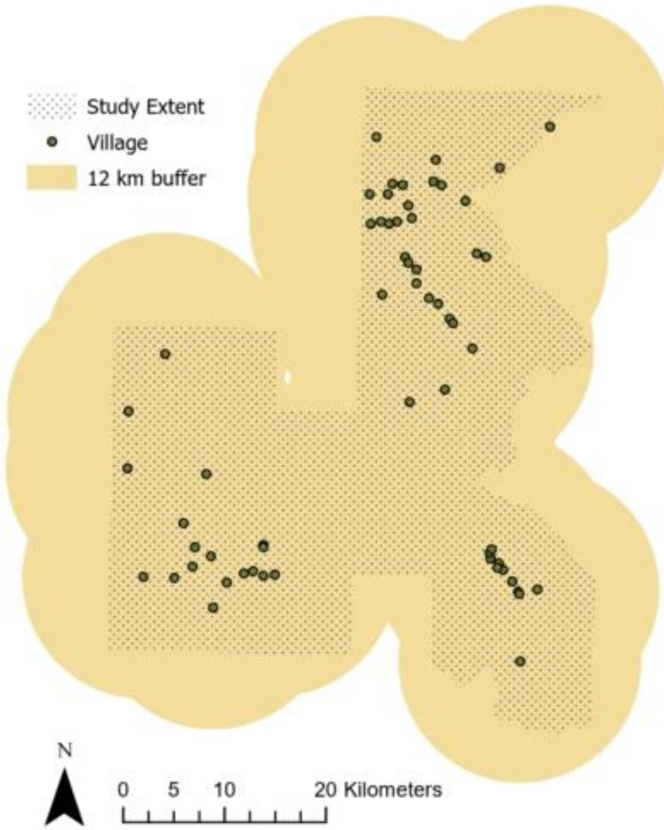

Figure 3.2: Livestock availability across our study extent. Each village was given a 12 km buffer to demonstrate where livestock could have roamed in the summer/fall when in high mountain pastures.

I also made the informed assumption that snow leopards are available throughout the entirety of our study extent. The home range size of snow leopards across the twelve countries the snow leopard is found can be anywhere from 12 km^2 to 1600 km^2 (R. Jackson & Ahlborn, 1989; T. M.

McCarthy et al., 2005). What is currently known about the home range of snow leopards in Nepal indicates a range of 12-39 km^2 in prime habitat, with a larger range in less suitable habitat (Jackson & Ahlborn, 1989). In addition, the snow leopard is capable of routine travel between 1-2 kilometers a day and periodic travel up to 20 km a day (Mccarthy & Chapron, 2003). Snow leopards are also known to make use of a variety of land cover types such as high elevation grassland and shrubland in Annapurna (Aryal, Brunton, Ji, Karmacharya, et al., 2014), whereas a preference to bare rock in China (Bai et al., 2018). Based off this information and the knowledge that our study extent as 1737 km^2 and the temporal extent of our study is 5 years, I assumed that snow leopards are available throughout the extent.

In conclusion, the availability of both snow leopards and livestock leads us to the overarching assumption that livestock were available to be killed by snow leopards anywhere in the study extent. Moving forward, this study focus its analysis on livestock accessibility: where livestock are most vulnerable to snow leopard depredation.

3.2.2 Data Requirements and Sampling Method

The data requirements for this research are the locations that livestock have been killed by snow leopards (dependent variable), and the environmental variables that may influence this location (independent variables). The sampling method for each will be examined in turn.

3.2.2.1 Livestock Kill Sites

We used a questionnaire (Appendix B) to collect information on the characteristics and location of livestock depredation events by snow leopards in our three study blocks. Similar studies have employed surveys to capture the location kill sites when a livestock depredation event is relatively infrequent and challenging to observe (Davie et al., 2014) We randomly selected households within our three blocks: Phoksundo (n=30), Dho Tarap (n=30), and Saldang (n=45). Surveys were completed over a 5-week trekking route in May-June 2022. A potential survey candidate was screened following the inclusion criteria of head of household and owner of livestock. If these inclusion criteria were met, then the respondent was asked if they experienced any livestock depredation by snow leopards over the past 5 years. If they selected yes, then they were asked about each unique event including type of livestock killed, number of livestock killed, season, and location. To ensure that each livestock kill site was an independent event, each additional point must have occurred 24 hours after the previous point but multiple livestock could have been killed in a single event (Miller et al., 2015).

Google Earth satellite imagery (Google, n.d.) was downloaded onto a field tablet in QGIS (v 3.22 long term release) with a 2-meter spatial resolution across the study extent prior to fieldwork. This resolution allowed for a fine-scale base map where individual houses, trails, fields, etc. could be easily identified. Each survey was conducted by 1 local research assistant from Dolpo and 1 researcher from the University of Waterloo. The local research assistant would orient the respondent with our current location on the Google Earth Imagery in QGIS, their home village location, and the locations of prominent land features such as rivers, walking trails, neighboring villages, and various grazing pastures. The respondent was then asked to identify the location(s) on the map that their livestock was killed, and a pin was placed on the corresponding location for each independent event.

I employed two tactics to ensure spatial accuracy of depredation sites. Firstly, our two research assistants grew up in Dolpo and have a rich spatial understanding of the landscape. This allowed them to orient the respondents on the QGIS map and discuss local landmarks and place names. Secondly, key informant surveys (n=6) were conducted within each block with members of the local Snow Leopard Conservation Committee. This allowed our local research assistants to corroborate local vernacular for place names and potential areas of conflict prior to conducting the surveys for the given block (Ramesh et al., 2022b) to better orient future respondents.

To ensure that each kill site was a location that a snow leopard had killed the livestock and not another large carnivore such as wolf, a knowledge validation question was included in the questionnaire. This question was open ended and asked how the respondent knew it was a snow leopard that had killed their livestock. Responses were verified by local snow leopard experts to indicate a snow leopard attack such as pug marks, scrapes, neck attack and blood sucked. Survey responses were removed from further analysis if the respondent could not indicate how they knew the killing was done by a snow leopard (n=2), or if the respondent gave an answer that was deemed ambiguous (n = 4) such as hole in stomach, vultures circling, or livestock spooked/running from something. Both tactics looked to ensure spatial and predator specific accuracy. This assumption moving forward is that each kill site is spatially accurate and correctly identified as livestock depredation by a snow leopard.

Finally, livestock depredation events were screened to determine which occurred outside of a night corral. This was possible as each respondent was asked whether their livestock depredation occurred while their livestock were being kept in a night corral. If the respondent selected yes, then this event was removed from further analysis (n = 35). This was decided because the underlying landscape features that influence depredation in rangeland could differ from corral locations. This left a final sample size of 155 independent livestock kill sites that were used in subsequent analysis.

3.2.2.2 Environmental Covariates

Spatial factors that may influence the location of livestock kill sites are the independent variables for this study. Commonly referred to as environmental covariates, these spatial factors are used as constraints to predict relative livestock accessibility to snow leopards, and therefore predict the high-risk areas livestock are most vulnerable to snow leopard depredation. While no predation risk model has been done on the snow leopard, a variety of environmental variables have proved to influence livestock vulnerability to large carnivores around the world. For example, density of settlements and land-cover had a strong influence on livestock depredation by tigers and leopards in Bhutan (Rostro-García et al., 2016), while proximity to rivers and low elevation were additional factors that strongly influenced livestock depredation by predators in Tanzania (Abade et al., 2014). Forest cover and altitude had a positive relationship to livestock predation risk for pumas in central Mexico, while distance from the livestock paddock to puma habitat had a negative relationship (Zarco-González et al., 2012). Such examples demonstrate influential variables are predator and perhaps even context specific. The decision on what covariates to include in our predation risk model were based off a combination of snow leopard ecology and other large feline livestock predation risk studies (table 4.1). Four categories of predictor variables were collected: topographic features, geographic features, human, and species.

Topographic features are important variables to consider as influencers of livestock vulnerability to snow leopards. Elevation was selected as is an influential factor based on both snow leopard biology and to livestock grazing patterns. Herders in this region practice transhumance which is the seasonal movement of livestock up and down in elevation levels with the seasons (Tiwari et al., 2020). Snow leopards have demonstrated to have an optimal elevation range that is bell shaped, such as 3,500 to 5,500 m near the mount Everest region (Bai et al., 2018). Elevation was then used to develop three more landscape features: slope, roughness, and distance to cliff. Slope was included as a predictor variable because snow leopards are also adapted to have a long tails that helps it balance when chasing prey in steep environments (Kitchener et al., 2016). As a result, snow leopards tend to gravitate to steep slopes at an angle greater than 40 degrees (Mccarthy & Chapron, 2003). Ruggedness and distance to cliff were both selected as potential indicators of cover. For any predator that relies on stalking prey as a hunting tactic, the ability to maintain hidden under cover increases the chance of hunting success (Yachi, 2000). While forest dwelling tigers or common leopard use vegetation as a means of cover (Miller et al., 2015; Soh et al., 2014; Zarco-González et al., 2012) the primary habitat of the snow leopard is high altitude in a treeless landscape. However, the snow leopard still relies on stealth to ambush prey, but cover takes a different form (Mccarthy & Chapron, 2003). The more rugged the landscape, the more potential for large rocks to offer cover for snow leopards (Bai et al., 2018). In addition, cliffs are known to be important habitat to the snow leopard (Mccarthy & Chapron, 2003), and could act as potential areas to spot prey. The final two landscape features selected are distance to gullies and distance to river. Snow leopards are known to like steep terrain such as those offered by ridges and gullies (Mccarthy & Chapron, 2003).

Four geographic classes were included as potential predictors of livestock accessibility. Distance to rock was selected for its potential to offer camouflage as the snow leopard has a rosette coat that blends into rocky landscape allowing it to stalk towards prey undetected (Hemmer, 1972). This camouflage was hypothesized to increase livestock accessibility. Distance to grassland was the second land cover included. Grassland exists throughout the study extent and could be areas that livestock spend more of their time and are easily spotted by snow leopards increasing their vulnerability. On the other hand, these areas could be those with more frequent human presence which could decrease livestock vulnerability as humans offer protection from snow leopard attacks. Snow leopards also show a preference for distance to rivers in their habitat suitability (M. Wolf & Ale, 2009). Both smaller gullies and larger rivers were then selected as potential predictor variables.

Human presence variables such as roads and villages could influence the vulnerability of livestock. Increased human presence in the form of roads and settlements has proven to decrease depredation risk for other large carnivores (Miller et al., 2015; Soh et al., 2014). However, other studies have found that depredation risk increases with increased with increasing density of settlements due likely to the increase in livestock density in these regions (Rostro-García et al., 2016). I therefor chose to include both distance to road and distance to nearest settlement as two predictor variables in our study. While a handful of larger roads exist in the region, SPNP most often uses trails as a means to travel between villages and transport goods via mules or yak. For the purposes of this study both roads and trails were combined into a single roads feature. I hypothesize that roads would decrease depredation risk due to the increase of human presence in these areas. Settlements are areas with permanent structures which similar to Rostro-Garcia (2016) could have increase livestock density and is therefore hypothesized to increase depredation risk.

Lastly, one species specific predictor was chosen as a potential indicator of livestock vulnerability: snow leopard habitat suitability. The range and density of snow leopards has been shown to vary based on habitat suitability (Jackson & Ahlborn, 1989; Mccarthy & Chapron, 2003). Habitat suitability of large carnivores in other PRM studies have shown to increase depredation risk such as the distance to dispersal corridors for lions in (Meena et al., 2014) and prime habitat for pumas (Kissling et al., 2009) A shapefile from WWF Canada that identified the prime habitat of snow leopards in SPNP was gathered.

Table 3.1: Landscape features hypothesized to influence the relative risk of livestock depredation by snow leopards, their data source, and references.

Category	**Predictor Variable**	**Data Source**	**Hypothesized Relationship**
Topographic Features	Ruggedness	Terrain Ruggedness Index (Riley et al., 1999) developed from the STRM 30 m	Increasing vulnerability with increasing ruggedness. Higher SL habitat suitability in more rugged landscape (Bai et al., 2018; Mccarthy & Chapron, 2003)

		Digital Elevation Model.	
	Distance to Cliff	Adapted from STRM 30 m Digital Elevation Model.	Increasing vulnerability closer to steep cliffs (>60 degrees).
	Slope	STRM 30 m Digital Elevation Model.	Snow leopard preference to steeper slopes (Bai et al., 2018; Mccarthy & Chapron, 2003)
	Elevation	STRM 30 m Digital Elevation Model.	Optimal range influencing snow leopard habitat suitability from 3,50 – 5,500 m (Bai et al., 2018).
Geographic	Distance to Rock	FRTC. (2022). Land cover of Nepal [2019].	Snow leopards primarily use barren land (Aryal, Brunton, Ji, Karmacharya, et al., 2014).
	Distance to Grassland	FRTC. (2022). Land cover of Nepal [2019].	SL habitat preference for grassland(Aryal, Brunton, Ji, Karmacharya, et al., 2014)
	Distance to River	ICIMOD. (2014) River Network of Nepal 2007. Kathmandu, Nepal: ICIMOD	Positive relationship with distance to river proves more suitable snow leopard habitat (Aryal, Brunton, Ji, Barraclough, et al., 2014; M. Wolf & Ale, 2009)
	Distance to Gullies	Nepal Survey Department (2015). Nepal Watercourses	Positive relationship with distance to river proves more suitable snow leopard habitat (Aryal, Brunton, Ji, Barraclough, et al., 2014; M. Wolf & Ale, 2009)
Human	Distance to nearest Village	OCHA Nepal (2015). Settlements in Nepal [2015]. OCHA.	Increased risk farther from villages (M. Wolf & Ale, 2009)
	Distance to nearest road	Nepal Survey Department, 2015	Increased risk farther from roads (M. Wolf & Ale, 2009).

Species	Distance to Prime SL Habitat	WWF Canada	Increased risk closer to prime snow leopard habitat. Proxy for density.

I used ArcGIS (v10.3.1) to prepare each predictor variable for modelling. Most of the original environmental data started as point, line, or polygon shapefiles (roads, large rivers, gullies, settlements, prime snow leopard habitat) taken from a variety of sources (table 4.1). The Euclidean Distance tool was then used to convert these shapefiles to raster format, where the value of each pixel is the distance (m) to the nearest feature. The same process was used for the land cover class rock and grassland however they began already in raster format. The elevation variable was taken from the Shuttle Radar Topography Mission (SRTM). This mission captured an open-source global digital elevation model with a 30 m resolution. This DEM was then used to generate three additional landscape features: slope, ruggedness, and distance to nearest cliff. Ruggedness was developed by generating a terrain ruggedness index originally presented by Riley et al. (1999) that characterizes the difference in elevation from a given pixel to that of its neighbors with each pixel value resulting from the following calculation: focal max – focal min / focal mean – focal min. Slope was generated using the slope tool in ArcGIS (v10.3.1). Distance to nearest cliff was developed by first selecting pixels from the slope raster with a steep angle above 60 degrees. This angle was selected through discussion with snow leopard specialists (personal communication, 2023) as it would signify a significant drop or ledge as mentioned is important to snow leopard hunting. This value is similar to other studies in mountain ecology where the escape terrain of mountain ungulates usually selects an angle of 45 degrees slope (Namgail et al., 2004; J. F. Wolf et al., 2022).

Finally, each of the predictor variables were clipped to the study extent with the same spatial resolution as the STRM satellite.

With these final 11 predictor variables, I ran a test to examine collinearity. Collinearity between predictor variables can inflate model performance (Merow et al., 2013). I ran the ENMTools package in R (v4.2.2, R Core Team 2022) to determine if any variables had a high correlation > 0.7. None of the 11 variables had high collinearity with one another (Appendix C). Therefore, I moved into our Maxent modelling with all 11 variables.

3.2.3 Hotspot Analysis of Livestock Kill Sites

The first assumption of species distribution modelling is that species occurrence records provide useful information about the environmental requirements of species occurrence (Phillips et al., 2006). Expanded to predation risk modelling, the first assumption is that occurrences provide useful information about the environmental requirements of occurrence. Moreover, there is a useful relationship between the environment and the occurrence sites. If this assumption was not met, the locations livestock are killed by snow leopards would be randomly distributed across the study extent as no underlying spatial factors would be driving the locations. I employed two techniques to test this assumption and determine if livestock kill sites are randomly distributed or clustered in space: Variance-to-mean ratio and Getis-Ord Gi* local statistic.

Variance-to-mean ratio is a measurement of clustering or dispersion in space. It uses the Poisson distribution under the assumption that if randomly distributed, the VMR = 1. Poisson distribution is common for count data applications. To transform our kill site locations to count data that could be used to calculate VMR, a grid was created to cover the extent of the kill sites. The grid cells were developed at multiple scales (1000m, 2000m, 3000m, 5000m), to investigate hotspots at a variety of scales. Each grid cell was then given a count value of the number of kill sites that fell within its boundaries. The VMR was then calculated for this grid with the count data per cell where a VMR > 1 indicates spatial clustering of data and a VMR < 1 indicates a uniform distribution.

The Getis-Ord Gi* statistic is a local measurement of clustering in space. It is a widely applied statistical method that measures spatial autocorrelation (Ord & Getis, 1995). The Getis-Ord statistic is calculated as follows (Ord & Getis, 1995):

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j} \right)^2 \right]}{n-1}}}$$

Figure 3.3 The Getis-Ord Gi* statistic that is used to examine spatial autocorrelation.

This statistic produces a Gi* statistic (z-score) by comparing the local sum for each feature and its neighbors to the expected value under a random distribution. Statistical significance occurs when the observed is very different from the expected score under random distribution. A positive statistically significant Gi* statistic indicates clustering of high values, while a negative statistically significant Gi* statistic indicates clustering of low values. Using the grid described above where each grid cell held count data of the number of kill sites within its boundaries, I applied the Getis-Ord Gi* statistics to determine the presence of statistically significant hotspots over the study extent.

3.2.4 Spatial Predation Risk Modelling: Maxent

The roots of spatial predation risk modelling (PRM) lie within the vast network of species distribution modelling. Species distribution modelling is a niche-based modelling approach which uses the occurrence of a species in combination with environmental covaries to predict the relative probability of occurrence across a landscape (Elith & Lethwick, 2009). This form of niche-based modelling, depending on the goal of its application, looks to predict the fundamental or realized niche of a species across the landscape of interest. The fundamental niche of a species is the entire area that a species could occupy given its environmental requirements, where a realized niche is a subset of its fundamental niche that only includes the areas where the species is actually present (Phillips et al., 2006). If the goal of a project is to create a new protected area for a species, then the realized niche would be of interest as you want to ensure the landscape you will be protecting has the species present, while the fundamental niche could be important to those looking to predict the spread of an invasive plant species. For the purposes of this research the realized niche is more appropriate as I are interested in where livestock depredation is occurring across the landscape.

PRM is an overarching term which captures a variety of methods that spatially investigate carnivore-human conflict. The most popular form of PRM is correlation modelling and studies which employ this method often have two objectives. The first is to develop a risk model to determine the influence of various spatial factors on livestock depredation, and the second to visualize the relative risk of livestock depredation across a landscape through hotspot mapping (Goljani Amirkhiz et al., 2018; Miller et al., 2015). Correlation modelling approaches vary but include generalized linear models, Maxent, and ensemble modelling (Miller, 2015).

I have selected Maxent as the most appropriate method to conduct this research due to the presence only nature of livestock kill data. Maxent is a common approach to presence-only species distribution modelling for habitat suitability (Phillips et al., 2006) and relative livestock depredation risk from large carnivores around the world (Goljani Amirkhiz et al., 2018; Rostro-García et al., 2016; Zarco-González et al., 2012). This type of modelling estimates the relative habitat suitability of a given species from 0 to 1 where 1 is highly suitable habitat (Senula et al., 2019). Maxent is based on the principle of maximum entropy, that uses presence-only data to predict the geographic distribution of a given species (Phillips et al., 2006). The principle of maximum entropy did not arise in the field of ecology. It is a statistical inference technique that has a long history of advancing a variety of fields such as thermodynamics, economics, and information theory (Thurner et al., 2017). Maxent has proved to produce the least-biased predictions that satisfy known system constraints (Jaynes, 1957; Jaynes, 1982). Entropy can be divided into three types: thermodynamic entropy, information entropy, and the statistical maximum entropy principle (Thurner et al., 2017). For the application to species distribution modelling, Maxent uses information entropy which is understood as the quantitative measure of uncertainty about an outcome (Harte & Newman, 2014). The formula used for Maxent is written as (Phillips et al., 2006):

$$H(\hat{\pi}) = -\sum_{x \in X} \hat{\pi}(x) \ln \hat{\pi}(x)$$

Figure 3.4: The formula from Phillips et al., (2006) used for the species distribution modelling technique Maxent.

The equation above takes the negative sum of the distribution of a pixel value in the study and multiplies it by the log probability distribution of that pixel to determine the entropy of that probability distribution $H(\hat{\pi})$. This formula is trying to determine the unknown probability distribution by choosing the one which maximizes entropy, or uncertainty, based on the known constraints of the system (Phillips et al., 2006). The more uniform a probability distribution, the higher the information entropy (Harte & Newman, 2014). This means that the probability distribution with the largest entropy would be a completely flat probability distribution, subject to no constraints. Therefore, the probability distribution that maximizes entropy would be the flattest distribution possible while still adhering to a set of constraints that are the environmental covariates in your system.

3.2.4.1 Sampling Bias

An assumption of Maxent is that presence points are randomly or representatively sampled (Phillips et al., 2006). If bias exists in these presence points, then this modelling process can produce unrealistic results (Kramer-Schadt et al., 2013). Difference methods to adjust for this spatial bias have been created and evaluated with context specific results (Fourcade et al., 2014). Overall, the two primary ways to adjust for sampling bias are either to filter the presence records or adjust where the background points are selected from. Removing presence records is known as spatial thinning. This technique eliminates presence points within a pre-determined distance of one another and has been employed by a variety of predation risk model studies (Miller et al., 2015), though this is not ideal or always possible for small sample sizes (Senula et al., 2019). The second to technique is altering the selection of background points which can be accomplished in a variety of ways. Firstly, if the sampling selection distribution is known, then models can be created using the same sample selection bias as the presence data and will produce a model the same as if the data were unbiased to begin with (Phillips et al., 2009). Such would be the case for breeding bird surveys where the sample areas are known (Merow et al., 2013). However, in the case for our study the sampling bias is not known. In other words, I do not know the bias of areas that respondents checked to see if their livestock had been killed by a snow leopard and those they did not. Another approach is through targeted group sampling if presence data exists of similar species that can then be used as pseudo-absence for the species in question (Phillips et al., 2009). However, this method is not possible for the context of livestock depredation as no similar taxon exist worthy of comparison.

A final technique, and the one that I selected to address sampling bias moving forward, is the creation of a bias file. A bias file represents the same sampling bias as the presence data and can be used for the selection of background points, though can generate weaker but often more realistic predictions (Kramer-Schadt et al., 2013). Other habitat suitability modelling studies had created the bias file through a Gaussian kernel probability density function (Chávez et al., 2018; Elith & Lethwick, 2009; Fourcade et al., 2014; Senula et al., 2019). This bias file was created and included into our model runs moving forward (figure 3.6).

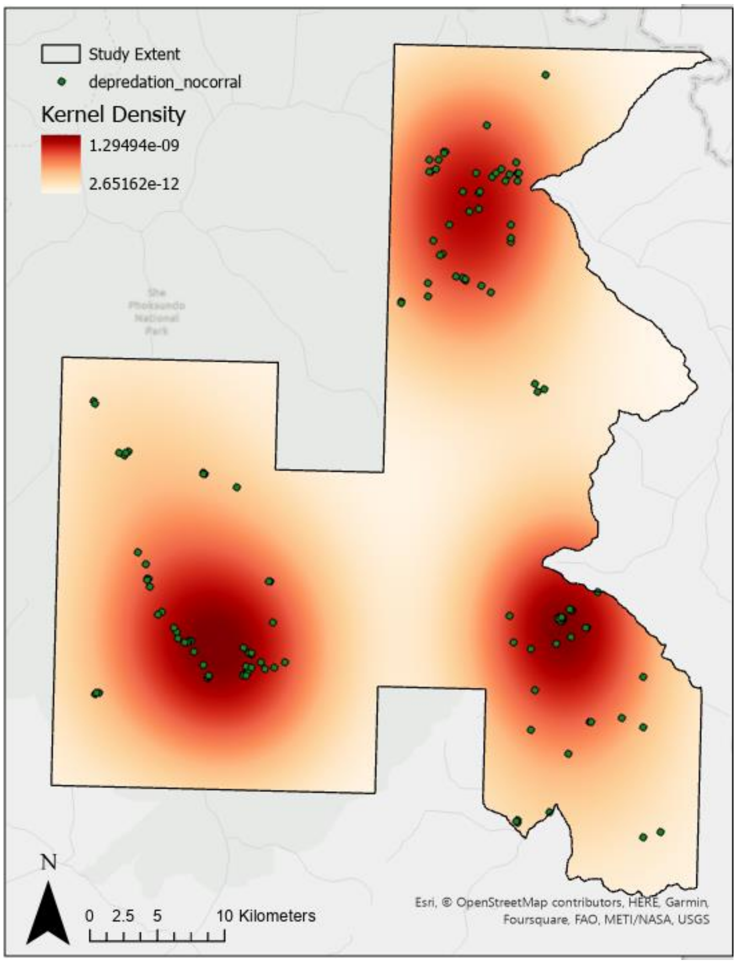

Figure 3.5: The spatial bias file created to show the sampling bias of livestock depredation records. Darker areas show more intense sampling bias in that region.

3.2.4.2 Maxent Assumptions

One assumption of maxent is that detection probability does not vary spatially with any of the predictor variables. The ability to detect an occurrence has often proven to vary with the same covariates being used to model occurrence (Yackulic et al., 2013). When applied to our context the question becomes: does the probability of detection for a livestock kill site change when our covariates change (e.g. does detection probability change with distance to water, elevation, slope, etc.)? I made the informed assumption that detection probability is constant. This was based on the nature of livestock herding in SPNP, where herders guide their livestock across pastureland commonly taking them multiple days walk from their home village (Gentle & Thwaites, 2016), and therefor across out study extent. In addition, livestock are an important livelihood to these households, and I believe that it is a realistic assumption that they would be able to identify the areas their livestock were killed by snow leopard consistently throughout the extent of our covariates.

Another assumption of Maxent is that presence points are independent of one another. This assumption is often critiqued as being frequently violated (Merow et al., 2013; Renner et al., 2013). I employed two methods to ensure that our depredation sites were independent events due to the fact that they were generated from our questionnaire. I generated the questionnaire with the knowledge that snow leopards are capable of killing multiple livestock in a surplus killing event. To handle this and ensure that each kill site was a unique and independent event I followed the methods similar to Miller et al., (2015) for tiger depredation on livestock. Each depredation event that occurred within a 24-hour period was treated as a single event (n=1), even if multiple livestock were killed over that time period. Secondly, I ensured depredation events were not duplicated between surveys by only recording the livestock lost to the individual household. This means that no two households would report the same livestock depredation event.

A final assumption with Maxent is that there is temporal correspondence between presence points and environmental covariates (Phillips et al., 2006). I have made the reasonable assumption that over the five-year period that livestock kill sites were recorded, there was no change in any of our environmental covariates.

3.2.4.3 Modelling Approach

Maxent is often critiqued as a black box. Researchers may not take the time to develop the right modelling approach to generate realistic models. Our approach was to ensure that final results were realistic and up to the current modelling standards. I completed our modeling process in R (v4.2.2, R Core Team 2022) in the package ENMeval (Muscarella et al., 2014). ENMeval runs Maxent by generating a series of candidate models with varying feature class and regularization multiplier settings and provides model evaluation criteria to evaluate model performance (Muscarella et al., 2014). I used a stepwise approach with the ENMeval package to select the best model and develop our final risk map. The best model was determined as the one with the lowest corrected Akaike Information Criterion (Warren & Seifert, 2011).

I addressed two sources of model complexity in order to ensure our model was realistic: number of predictor variables, and model parameters. A large critique of Maxent is the default setting use of the model parameters feature class and regularization multiplier (Yackulic et al., 2013). A feature (predictor) is the ecological assumption your model makes about the distribution of a given species, which is why they are referred to as the constraints in Maxent (Elith et al., 2011). A feature constrains the distribution of the species in question. Transformations are applied to features which influence the complexity of the Maxent model, and there are six transformations available: linear, quadratic, product, threshold, binary, and hinge (Phillips et al., 2006). The transformation applied to covariates influences another parameter: regularization. This parameter addresses the assumption that Maxent makes when using the mean equal to the mean of the empirical observations in the modelling process, which results in overfitting models, by expanding possible values to a given interval around the mean (Warren & Seifert, 2011). The regularization multiplier is applied to each feature with a default value, depending on the transformation, based on the application of Maxent to 226 species for six different geographic regions across the world (Phillips et al., 2006). While this parameter can be changed it is often ignored, which can influence the ability of Maxent models to predict habitat, the importance of environmental variables, and the transferability of models (Warren & Seifert, 2011). Few studies take the time to determine the most appropriate model parameters, despite the parameter settings producing far more reliable models (Morales et al., 2017).

This modelling approach required two separate runs of the ENMeval package. The first one was exploratory to investigate the relationship between livestock depredation sites and the 11 biologically significant predictor variables. This was based off of the understanding that more complex models are often inflated, and predictor variables should be rigorously chosen.

I included five combinations of feature class and a regularization multiplier between 1 – 5. I then examined the output of this run and investigated the variable contribution of the top performing model. If any variable demonstrated a low percent contribution of less than three percent to the relative livestock depredation risk, it was removed. This resulted in the removal of distance to prime snow leopard habitat, distance to gullies, terrain ruggedness, and slope.

I then conducted out second run of the ENMeval function. This was run with the reduced number of predictor variables. The same variation in feature class and regularization multiplier was allowed. The final model selected was the model with the lowest AICc value.

3.2.4.4 Model Evaluation

The best model needs to be replicated to determine if results are consistent (Morales et al., 2017). The default model evaluation of k-fold cross validation was not selected to validate our model as is has proven to overfit based on spatial autocorrelation of training and test data (Veloz, 2009). Spatial autocorrelation between a species presence location and the environmental covariates are a critical component of the modelling process (Sillero & Barbosa, 2021). However, the autocorrelation between training and testing data must be addressed properly in order to make accurate and realistic model predictions (de Oliveira et al., 2014). Two partitioning methods exist that account for spatial autocorrelation: block and checkerboard. While block is growing in popularity it is most often appropriate when expanding to new regions of predicting under climate scenarios, checkboard may be desirable when the transferability of a model is not required as this technique is less likely to extrapolate (Muscarella et al., 2014). Due to our study objectives of developing a relative risk map over a reduced spatial extent I have decided to move forward with the checkerboard method. There are two variations of checkerboard, and I selected the “checkerboard2” partitioning method to evaluate the model. This separates presence data equally across the study extent into a checkboard pattern with four distinct bins opposed to two bins with checkerboard1 (Muscarella et al., 2014). Each run of the model included three bins as training data and one bin as test data. This was repeated until each bin was used for testing and model results are an average of the four runs. As previously mentioned, the model with the lowest AICc was selected. The prediction of the best model of relative depredation risk was exported into ArcGIS to produce the final relative risk map.

3.3 Results

The results begin with summary statistics regarding the livestock holdings and the characteristics of livestock depredation such as livestock species, season, and occurrence in corral. Results will the present the local measurements of livestock depredation through the variance-to-mean ratio and the Getis-Ord Gi statistic. The final section of the results presents the output of the Maxent spatial predation risk model. The results demonstrate which variables are the most influential drivers of the intensity of conflict and the areas most at risk for future livestock depredation.

3.3.1 Summary Statistics: Livestock Depredation

The quantitative questionnaire collected a variety of information on the occurrences of livestock depredation that will be reported here beyond the spatial location of the kill site. Respondents were asked about the characteristics of each livestock depredation event in the past 5 years. A total of 214 unique cases of livestock depredation were reported (n=105). To ensure an accurate comparison of these characteristics the total occurrences were reduced to the past 3 years to ensure accuracy of reporting and replicate similar reporting of other snow leopard studies (Hanson et al., 2019). In addition, this allows for characteristics such as season to be fairly compared as data was collected in spring of 2022 not allowing for data on summer and fall depredation in 2022 which could result in heavier weights to spring and winter depredation. Therefore, the past 3 years included winter and spring of 2022, all of 2021 and 2020, and summer and fall counts of depredation in 2019. This reduced the total number of unique occurrences of livestock depredation from 214 to 185.

Results indicate that a total of 812 livestock were reported as killed by snow leopards over the past 3 years, for an average of 2.6 livestock/household/year. The livestock targeted most frequently by snow leopards were goat & sheep (82%), followed by yak & nak (11%), then horse & donkey (4%). Cow (0.7%) and hybrid livestock (1.9%) accounted for very few livestock deaths by snow leopards. The season where most depredation occurred was winter (41.1%). The other season were relatively evenly distributed with spring (23.2%), summer (17.8%), and fall (14.6%). Respondents were also asked whether their livestock were in a corral at the time of attack. Most attacked occurred when livestock were not kept in a corral and instead roaming freely (79.5% of total occurrences), accounting for half of the total livestock killed (51.3%). Attacks by snow leopards of livestock inside a corral occurred less frequently (16.8% of total occurrences), however accounted for a proportionally larger number of livestock killed (40.3%). This demonstrates that attacks of livestock in corrals are less frequent but more intense than the attacks that occur when livestock are out roaming in their grazing pastures. The remaining depredation recorded did not indicate if the event occurred inside or outside a night corral, which explains why the previous numbers do not total 100 %.

3.3.2 Local Measurements of Livestock Depredation Sites: Hot Spot Analysis

Our local statistics determined that there are hotspots of livestock depredation events. Nearest neighbor statistic indicates statistically significant clustering with an observed mean distance of 499 m compared to an expected mean distance of 1706 (z-score: -19.14, p-value 0.00). I assessed livestock depredation events at multiple scales which all revealed significant clustering in space through the variance to mean ratios (table 3.2)

Table 3.2: The variance-to-mean ratios for our study extent at varying quadrat resolutions

Quadrat Resolution (m)	Variance to Mean Ratio
1000	5.19
2000	6.07
3000	7.11

5000	10.4

A local Getis-Ord Gi values also indicate where statistically significant clusters of hotspots exist on our study extent. For example, a quadrat resolution of 2000 m exhibit three hotspot clusters (figure 3.8). The local Gi results at all of the quadrat resolutions can be found in the appendix (Appendix D). These hotspots also occurred at the resolution of 1000, 3000, and 5000m and shown above.

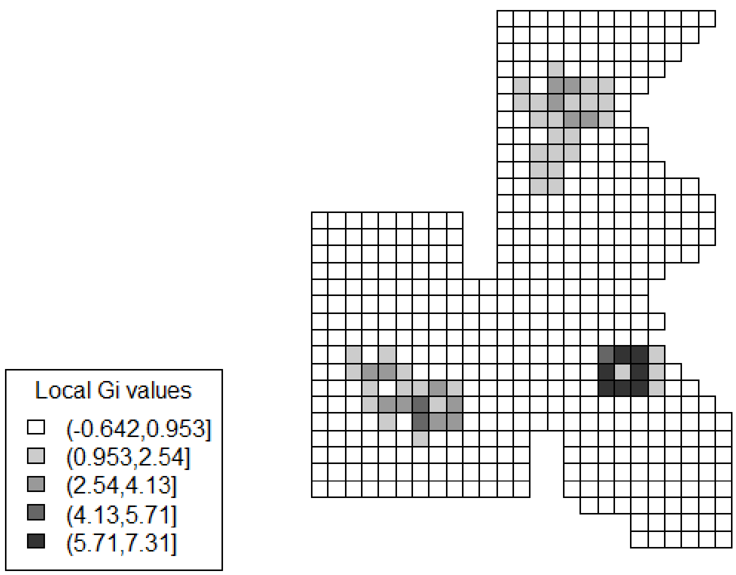

Figure 3.6: The Local Gi Statistic indicating the locations of hotspots of livestock depredation.

3.3.3 Spatial Predation Risk Modelling: Maxent

The model parameters of our best performing model with the lowest AICc had the feature classes of linear and quadratic, and a regularization multiplier of 1. This model included seven variables that had a contribution > 3 percent: distance to grassland, village, rock, roads, cliffs, large rivers, and elevation. The contribution of variables in descending order from most to least important are distance to grassland (37.3%), distance to large rivers (25.0%), distance to village (18.4%), elevation (6.1%), distance to road (5.0%), distance to nearest cliff (4.5%), and distance to rock (3.5%). Permutation importance followed a similar pattern but with distance to large rivers having the greatest important (33.8%) and elevation surpassing distance to village for third place (15.1%) (table 3.3).

Table 3.3: The percent contribution and permutation importance of the predictor variables in our top performing model.

	Percent Contribution	**Permutation Importance**
Distance to grassland land cover	37.3	24.5
Distance to large rivers	25.0	33.8
Distance to nearest village	18.4	7.7
elevation	6.1	15.1
Distance to nearest road	5.0	6.4
Distance to nearest cliff	4.5	6.6
Distance to rock land cover	3.5	6.0

Most variables had a negative relationship with the relative risk of livestock depredation (figure 3.9). Moreover, depredation risk decreases as distance from our predictor variables increases (grassland, villages, rivers, cliffs, and rock). Distance to roads shows an initial decrease in depredation risk from low to moderate distances from roads, but the demonstrates an increase in depredation risk at moderate to far distances from roads. Distance to grasslands shows the steepest decline in depredation risk, with very little risk occurring 500 after meters away from grasslands.

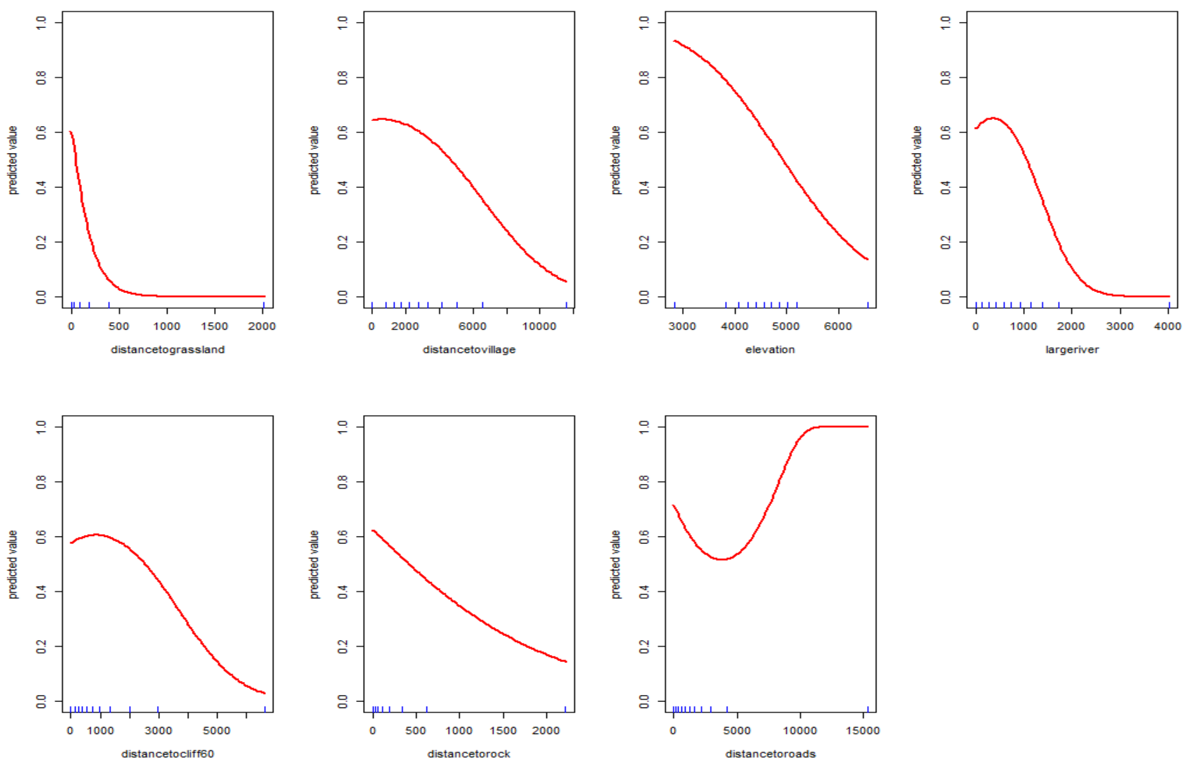

Figure 3.7: response curves for each predictor variable. This compares the value of each response variable to the relative risk of livestock depredation when other variables are held constant.

The average Area Under the Curve (AUC) testing value of our best performing model is 0.77 (table 3.4). This suggests that this model has a good overall performance in its ability to distinguish the relative risk of livestock depredation (Goljani Amirkhiz et al., 2018). The average AUC difference is low (0.027) suggesting that the model is not subject to overfitting (Warren & Seifert, 2011). The threshold-dependent evaluation criteria also indicate a good model, with a mean omission rate near 0.10 (0.11) and a low mean omission rate, also known as presence threshold (0.0061). Models with lower omission rate indicate good performing models that are not subject to overfitting (Anderson & Gonzalez, 2011).

Table 3.4: Model parameter and evaluation criteria of the top 4 performing model. B = regularization parameter, L = linear, Q = quadratic, H = Hinge, P = Product, T = Threshold.

Feature Class	**B**	**delta AICc**	**Mean AUC**	**Mean AUC Difference**	**Mean Omission Rate (10%)**	**Mean Min Omission Rate**	**Number of Parameters**
L, Q	1	0	0.77	0.027	0.11	0.0061	11
L, Q	2	2.25	0.77	0.022	0.11	0.018	8
L, Q	3	8.85	0.76	0.024	0.12	0.018	9
L, Q, H, P, T	4	9.16	0.78	0.043	0.17	0.012	28

The predictions from our best performing model of the relative risk of livestock depredation were mapped to visualize the hot spots where livestock are most vulnerable (figure 3.10).

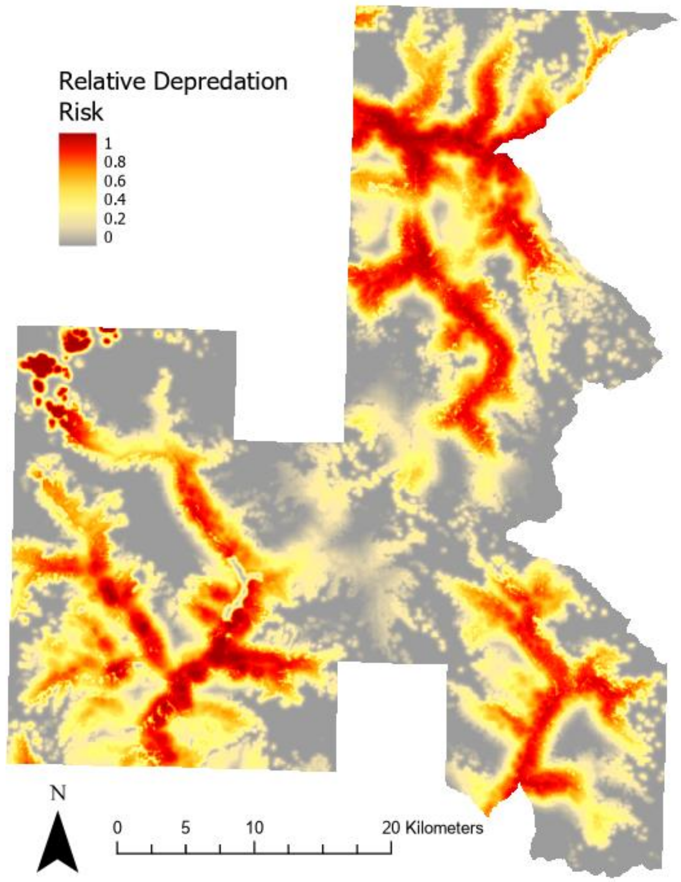

Figure 3.8: the relative risk of livestock depredation from snow leopards. Warmer colors indicate a higher relative depredation risk.

3.4 Discussion

Retaliation against snow leopards as a result of livestock depredation is a significant threat to snow leopard survival. Data on the spatial locations of livestock depredation are scarce and few studies have looked to identify these conflict hotspots on the landscape. This research provides a relative depredation risk model that identifies the hotspots of our study extent which can aid in determining priority areas for conflict management efforts. In addition, landscape features associated with higher relative risk can be considered by local communities when engaging in livestock husbandry or implementing their own mitigation measures.

3.4.1 Livestock Depredation by Snow Leopards

Our results demonstrate that livestock are being killed by snow leopards in Shey Phoksundo National Park. Goat and sheep were the most commonly killed livestock, followed by yak or nak. These results are similar to a past study of snow leopard diet in the region that identified livestock in thirty percent of snow leopard scat with sheep as the most common livestock (B. Devkota et al., 2013). This differs slightly from scat analysis studies in the neighboring Annapurna region, that found goats and horses most common with very few yaks and sheep depredation (Chetri et al., 2017). These differences could be a result of a variety of factors with the most plausible being differences in livestock availability between the two regions. In terms of the seasonality of livestock depredation our research found most depredation occurs in the winter (41%). This finding mirrors other studies on livestock depredation that also found winter as the most frequent season for livestock depredation by snow leopards (Devkota et al., 2013; Oli et al., 1994; Aryal et al., 2014). Our results also demonstrate a livestock depredation event more frequently occurs when livestock are roaming free in the mountains opposed to kept within night corrals. Interestingly, despite attacks on livestock in night corrals only accounting for 17% of all reported depredation events, these attacks account for 40% of all livestock lost. This demonstrates that attacks on livestock in corrals are less frequent but more intense than attacks that occur when livestock are out roaming in their grazing pastures.

3.4.2 The Relationship Between Livestock Depredation and the Environment

The environmental variables most important to a higher relative risk of livestock depredation are distance to grassland, large rivers, and villages. Grassland is an important land cover to both the snow leopard and livestock. Snow leopards have shown a preference to these high mountain grasslands, while livestock are driven to these pastures for grazing. Similarly, large rivers offer important habitat to both livestock and snow leopards in this region. For livestock, this offers areas to drink and graze, while for the snow leopard this leads to higher habitat suitability offering areas with steep ridges to potentially scan for prey (M. Wolf & Ale, 2009). As distance away from nearest village increased livestock depredation in our study proved to decrease. Other studies have found a similar negative relationship between large carnivores are distance to settlements likely due to the increase in livestock density near these areas (Rostro-García et al., 2016). If we consider all forms of depredation by snow leopards to include those events that occurred in night corrals, the importance of this variable would only be strengthened. This is because our study chose to eliminate depredation events that occurred in night corrals, which are often near villages with some even attached to individual houses. While human presence is often found as a deterrent to livestock depredation for other large carnivores such as the tiger (Miller et al., 2015; Soh et al., 2014), it may not be the case for the snow leopard. Another potential explanation for this relationship could be due to the transhumance of livestock in this region and the season of depredation. Our study found that winter was the most common time for livestock depredation (41%), and in the winter months livestock are brought to winter pastures closer to villages. The highest depredation during the winter months, and this relationship between distance to village and depredation risk, could suggest that villages do not act as much of a deterrence as potentially thought.

Additional variables that contributed to the relative risk of livestock depredation are elevation, and distance to roads, cliffs, and rock land cover. Distance to rock showed a negative relationship which demonstrates depredation risk decreases the farther you get from the rock land cover class. While one might think that this could be due to a relationship between rock and grassland land cover features, no correlation between the two variables existed with a correlation of 0.01. This relationship could be due to the ability for this land cover type to offer camouflage to the snow leopard (Hemmer, 1972). Distance to cliffs was another variable selected due to the hunting techniques of snow leopards. The ability to remain hidden when ambushing prey is important to large carnivores that are ambush hunters (Yachi, 2000). Because snow leopards are ambush predators it comes as no surprise that cliffs have been identified as important landscape features (Mccarthy & Chapron, 2003). Our results support these findings as the relative livestock depredation risk increases the closer you get to cliffs. Elevation also demonstrated a negative relationship to the risk of livestock depredation. This could be a result of livestock grazing patterns. The seasonal movement of livestock could offer one explanation to this relationship as herders practice transhumance and bring livestock to lower elevation in the winter months (Tiwari et al., 2020). Due to the fact our study showed that most depredation occurs in winter this could result in the negative relationship observed. Lastly, distance to roads showed a variable relationship. Depredation risk begins at a moderate level which decreases until around a distance of 5000m, only to increase again at far distance. The spike in relative depredation risk at far distances could be explained by many depredation events occurring in the northwest extent of our study where no roads exist. Areas slightly off the road could also have greater human presence or are more easily guarded by humans resulting in less depredation risk than areas farther away from roads.

Variables that were removed due to their minimal influence of livestock depredation were distance to prime snow leopard habitat, slope, terrain ruggedness, and gullies. These environmental variables had first been identified due to their importance for snow leopard biology and ecology. For the case of prime snow leopard habitat, this finding differs from other predation risk studies that have shown a positive relationship between puma habitat suitability and depredation (Kissling et al., 2009). Though this result does show some similarity to another study that demonstrated snow leopard density did not appear to have any significant influence on livestock depredation (Chetri et al., 2017). These results could be observed due to the complex relationship between snow leopard, livestock, and wild prey species. This could also suggest that prime snow leopard habitat may not necessarily offer optimum accessibility to domestic livestock. Slope and terrain ruggedness providing no major contribution to livestock depredation could suggest that these two variables have a small influence on livestock vulnerability in our study extent. Slope was selected as the snow leopard is adapted to hunt wild prey on steep slopes (Kissling et al., 2009). This outcome suggests that while slope may be an important factor when hunting wild prey, it is not a driving factor behind where livestock are being killed. The lack of a significant contribution does not mean that slope is constant across kill sites, rather that no significant pattern exists between the angle of slope of a given pixel and the risk of depredation. A similar reasoning can be applied to terrain ruggedness. This variable was selected due to its potential to offer cover while stalking prey (Bai et al., 2018), however it showed little contribution to the relative risk of livestock depredation. Distance to gullies were the final variable excluded due to small contribution. Gullies can offer steep terrain that snow leopards have shown a preference for (Mccarthy & Chapron, 2003). Their small contribution when compared to large rivers could be due to the fact that they are smaller and more numerous across the study extent, offering less steep habitat and more homogenous values that how larger rivers would influence the landscape.

3.4.3 Potential Management Implications

The results from this analysis and final hotspot map could be used to guide future management implications implement by local communities, government, or NGO's. This research addresses the call for a spatial analysis of livestock depredation events to outline hotspots and predict future areas of conflict made by the Snow Leopard Conservation Action Plan (DNPWC, 2017).

This spatial knowledge of depredation hotspots can be used by the local community to alter their husbandry practices in the areas that livestock are most vulnerable to depredation (Rostro-García et al., 2016). In the case of the snow leopards, techniques can be chosen based on patterns of depredation and could include increased guarding in winter and calving season, better breeds used as guard dogs, or the hiring of skilled herders to monitor livestock (Jackson et al., 1996). Our study highlights the understanding that most livestock depredation events occur in winter and close to human settlements could be used to guide education and awareness initiatives. A local understanding of the need to increase human presence in winter months when livestock are close to villages could result in a decreased risk of depredation. Our results also show that the intensity of livestock depredation is more severe within night corrals compared to when livestock are free to graze. This could have management implications as a way to highlight the dangers of keeping livestock in a poorly constructed night corral, which could perhaps be even more harmful then when livestock are free to graze. This hypothesis would need to be investigated through the analysis of night corral construction relative to depredation events, similar in design to the study conducted with Bomas in Tanzania (Meena et al., 2014). In addition, this suggests the importance of the investment into predator proof night corrals in the region.

An understanding of the spatial locations of livestock depredation can be used to target future mitigation techniques by the local government of NGO's. Predator-proof night corrals have been implemented in a few areas in the park to date. The increase of severity of livestock depredation events within traditional night corrals can be used as justification to continue this critical mitigation program in the region. In addition, our predation risk map can be used as a tool when deciding the placement of future predator proof night corrals. The communities that fall in these areas of high livestock depredation risk can also be prioritized for future mitigation measures such as education and awareness campaigns, or tourism opportunities. However, how depredation events change following the placement of these corrals should be monitored. A study that examined theoretical models for human-wildlife conflict demonstrated that livestock depredation could be better controlled in highly productive habitats rather than lowly productive habitats (Bagchi, 2019). The study used the strategy of predator proof night corrals as an example: if placed in a low suitability habitat for the snow leopard night corrals could be detrimental as they eliminate a vital food source (Bagchi, 2019). Lastly, areas with high livestock depredation could mean a high snow leopard presence and may offer valuable snow leopard tourism opportunities to the region. Tourism opportunities could be explored further in future studies.

3.5 Conclusion

Our study demonstrates the novel application of predation risk modelling in Maxent to livestock depredation by snow leopards at a fine spatial scale. Our model proves robust and a good predictor of the relative livestock depredation risk. These results demonstrate that grassland, distance to major rivers, and distance to villages are the variables which contribute the most to relative depredation risk. Other variables with smaller contributions include elevation, distance to cliffs, distance to rock land cover, and distance to roads. Variables which Ihypothesized to influence livestock depredation but proved as poor contributors are prime snow leopard habitat, gullies, terrain ruggedness, and slope. Local communities and snow leopards are going to continue to exist in this landscape and mitigation strategies can address these spatial drivers of livestock depredation risk. In addition, locations which livestock are most vulnerable can be prioritized in future conflict mitigation effort. Predation risk modelling is designed to be an adaptive process, and while our model provides a good snapshot of predation risk today, I encourage a continued and long-term investigation on depredation risk after management actions are taken.

Chapter 4: Attitudes Towards Snow Leopards in Shey Phoksundo National Park

4.1 Introduction

To ensure that economic development needs are being met in the name of snow leopard-human coexistence, conflict resolution strategies will need to be informed by the needs and perceptions of local communities. It is well understood that there are consequences of human-carnivore conflict that go beyond physical attacks or property loss. The negative consequences such as psychological fear, risk, or tolerance of a species are far more challenging to quantify but equally important in managing for coexistence (Kansky et al., 2014). This chapter applies a social lens to investigate the human dimensions of conflict with snow leopards in SPNP through the investigation of local attitudes.

4.1.1 Importance of Social Science in Human-Carnivore Conflict Research

The social sciences are a critical field of research in studies on carnivore-human conflict. This field began with a heavy emphasis on the natural sciences. Research in human-carnivore conflict often uses livestock loss as an indicator for conflict and reduction of livestock loss as the indicator of coexistence (Bagchi & Mishra, 2006; van Eeden, Crowther, et al., 2018; van Eeden, Eklund, et al., 2018). However, there is growing recognition of the importance of research into the human dimensions of conflict to fully address the complexities of these conflict scenarios. Human dimension research can investigate what has been coined as "perceived conflict" – the perception of conflict felt by communities involved. There is often a proven mismatch between how a local community perceives carnivore-human conflict and the actual level of conflict endured (Dickman, 2010). For example, intangible costs such as psychological, fear, and risk, have been demonstrated as far more significant when explaining attitudes towards wildlife involved in conflict than tangible costs such as number of livestock killed (Kansky et al., 2014). In a separate example, number of livestock killed by snow leopards was not a significant factor influencing attitudes towards snow leopards in Nepal and India (Hanson et al., 2019; Suryawanshi et al., 2014). This suggests the importance of underlying social drivers outweighs the physical manifestation of conflict when examining attitude towards large carnivores. A similar discussion has emerged when investigating carnivore-human coexistence. There is an emerging call for the evaluation of mitigation strategies to reveal if they do in fact promote coexistence (Dickman, 2010; Eklund et al., 2017; Graham et al., 2005; Holland et al., 2018; Miller, 2015). However, assumptions are often made that direct managers to coexistence strategies targeted only at the reduction of actual conflict: (A) that the level of wildlife damage is directly related to the level of conflict engendered; (B) that the level of conflict elicits a proportionate response; (C) that altering the response to conflict will have proportionate conservation effects (Dickman, 2010). It is clear that if coexistence is the goal, research into the human dimensions of these conflicts are a critical component of research that should be applied more frequently in the field of carnivore-human conflict.

4.1.2 Study Objectives

Attitudinal research is a field of research rooted in psychology that has been applied broadly across field such as political science, marketing, communications, and sociology. This field of research can also address human dimensions of carnivore-human conflict. For this thesis, “attitude” is defined as the tendency to respond with some degree of favorableness, or not, to a psychological object, the object representing any element of an individual’s world such as an object, person, or behaviour (Fishbein & Ajzen, 2010). This definition of attitude places attitude along a continuum, from negative to positive, passing through a point of neutrality (Fishbein & Ajzen, 2010). It is important to note there is a difference between attitude and behaviour. An individual’s attitude of the natural world can define their actions (Kareiva & Marvier, 2012). It should be noted that gaps between attitude and behaviour particularly in the field of conservation and protected areas have been identified (Lai & Nepal, 2006). It should be understood that attitudes themselves are not behaviour and do not explicitly determine behaviour, rather attitudes have been proven as a necessary condition for behaviour (Heberlein, 2012; Kansky & Knight, 2014). When brought to the context of snow leopard-human conflict, this could suggest that positive attitudes alone cannot predict if an individual will engage in positive behaviour regarding snow leopards, but a positive attitude could be a necessary component for positive behaviour. Despite this understanding, few studies have utilized attitude research in the examination of snow leopard – human conflict (Hanson et al., 2019). To address the gap, this proposed research will investigate livestock owner attitudes towards snow leopards through the following research questions:

I) What are local community attitudes towards the snow leopard?

II) What are the determinants of attitudes of local communities towards snow leopards?

This research has the applied goal of informing mitigation strategies that aspire for coexistence grounded in social dimensions of coexistence. An understanding of local attitudes could inform future mitigation strategies through a targeted approach to villages with the most negative attitudes, and an understanding of attitudinal drivers could inform mitigation strategies to target the most influential factors influencing attitude.

4.2 Methods

This section presents the methods used to understand attitudes of local communities in SPNP to snow leopards. To begin, this thesis provides an overview of the study location of Shey Phoksundo National Park. It then outline the sampling and survey design of the quantitative questionnaire used to capture local attitudes. This section includes the hypothesized relationship between potential explanatory variables and attitude, and outlines how a composite attitude score was used to capture respondent attitude. This section ends by outlining the procedures used in the creation of general linear models to identify which explanatory variables proved the most influential on local attitude towards snow leopards.

4.2.1 Study Area

Shey Phoksundo National Park (SPNP) was the chosen protected area to answer our two attitudinal research questions. SPNP falls under the district of Dolpo in the Karnali Province of Nepal. Dolpo is the largest district in Nepal and SPNP is the largest National Park in Nepal spanning 3555 km^2 with an additional 1350 km^2 in the surrounding buffer zone (DNPWC, 2017). A rich amount of biodiversity exists in this region, including 32 mammal species and nearly 200 bird species (Kusi et al., 2018). Many of these species are vulnerable to extinction such as the snow leopard, wolf, Himalayan black bear, and musk deer (Devkota et al., 2013). Communities have occupied this remote region of Nepal for many generations. With little access to resources the main source of income includes livestock husbandry, agriculture, and non-timber for product collection (Kusi et al., 2020).

There are two main divisions to SPNP: Lower Dolpo and upper Dolpo. While both regions fall within park boundaries, they differ in remoteness, livestock holdings, snow leopards, and livestock depredation. These differences make them ideal to investigate attitudes towards snow leopards. Firstly, there is a variation in geography between the two regions. Lower Dolpo receives 1500 mm of rain annually and supports a mixed broadleaf and coniferous forest, while Upper Dolpo lies in the rain shadow of Tibet and only sees 500 mm of rain annually (Khanal et al., 2020). Secondly, there is a variation in the communities that live within SPNP. Lower Dolpo is home to 550 people spread across 4 main villages who have reduced their small livestock holdings due to an increase in tourism presence, but still rear large livestock such as yaks and horses (Khanal et al., 2020). In Upper Dolpo there are over 2,500 inhabitants with less tourism opportunities and an average livestock holding of 40-per household animals consisting of both small livestock and large livestock (Khanal et al., 2020). Thirdly, there is a variation between the two regions for snow leopard densities. The density of snow leopards in lower Dolpo at 1.2 individuals per 100 km^2, with upper Dolpo is double at 2.5 snow leopards per 100 km^2 (Khanal et al., 2020). An additional study suggested that this region is home to the highest density of snow leopards in the country at 3.2 individuals per 100 km^2 (DNPWC, 2017). The variation in snow leopard density reports for this region mirror the rest of Asia due to the elusive nature of this predator and the remoteness of its habitat. Despite a variation in density, there is no debate as to the importance of this region to snow leopard habitat. Of the total protected area size, 90% is classified as potential snow leopard habitat (DNPWC, 2017). Livestock depredation has been reported in both regions. One study recorded just over 3% of total livestock holdings lost to snow leopard depredation in a single calendar year in Lower Dolpo, and 10% in Upper Dolpo (Khanal et al., 2020). Despite this known conflict, little social science research has been completed in SPNP to date. A single study investigated attitudes towards snow leopards in this region but did not make any conclusions beyond descriptive statistics (Kusi et al., 2020). The attitudinal and drivers of perceived conflict are left largely unknown.

4.2.2 Sampling and Survey Design

Our target population were heads of household who own livestock and live within the boundaries of Shey Phoksundo National Park. The inclusion criteria of owning livestock were chosen as only these households would be susceptible to livestock depredation, data required in the natural science portion of this thesis. While most individuals in SPNP own livestock, it should be noted that those who did not were excluded from this research and therefor limiting this research and its findings to livestock rearing households. There are 772 households in SPNP (Khanal et al., 2020), and our targeted sample size was 10% - 15% of households which would result in a total intended questionnaire sample between 72 – 115 households. Prior to conducting the questionnaire, a University of Waterloo ethics approval was completed (ORE#43202).

Over the months of May and June 2022 we conducted 105 questionnaires in SPNP. Households were randomly selected – each with an equal chance of being chosen. Due to the remoteness and vastness of SPNP, a 5-week trekking route was established in consultation with WWF Nepal. This route focused on three major village clusters: Phoksundo, Dho Tarap, and Saldang. Villages clusters were chosen to include both Lower Dolpo (Phoksundo and Dho Tarap) and Upper Dolpo (Saldang). These three villages are where the majority of the population within SPNP lives ensuring the feasibility of our intended sample size. Within each cluster we conducted random sampling of households in Phoksundo (n = 30), Dho Tarap (n = 30), and Saldang (n = 45). This resulted in a sample size for Lower Dolpo of 60, and a sample size of Upper Dolpo of 45.

A targeted questionnaire was designed to collect the information required to answer our two research questions (Appendix B). This questionnaire included mainly quantitative closed ended questions, but included a few open-ended questions designed to capture the reasons behind certain answers as suggested when designing ecology questionnaires (White et al., 2005). Important themes to include in the questionnaire were identified through the investigation of past quantitative studies on attitudes towards large carnivores around the world (Hanson et al., 2019; Kusi et al., 2020; Suryawanshi et al., 2014; Uduman et al., 2021; Zimmermann et al., 2005) After review, the questionnaire was developed to collect information on six themes related to snow leopard human conflict: Socio-demographic variables, livestock holdings, snow leopards & depredation, attitudes towards snow leopards, livestock husbandry & mitigation techniques, and attitudes towards snow leopard conservation (Table 5.1).

Table 4.1: Themes of questionnaire protocol identified through other studies on large carnivore-human conflict, and a sample question from the questionnaire.

Survey Themes	**Example Question**
Socio-demographic	What is your age / sex / education level?
Livestock Holdings	How many livestock do you own?
Snow Leopards & Depredation	How many livestock have you lost to snow leopards in the past 12 months?
Attitudes of Snow Leopards	How do you feel about the following statements: snow leopards deserve protection
Livestock Husbandry and Mitigation	Was your household compensated through an insurance scheme the past 12 months?
Attitudes towards Snow Leopard Conservation.	How do you feel about the following snow leopard conservation strategies: predator proof night corrals?

Questionnaires in the field of ecology are used to test a hypothesis based on information from a human population such as quantifying perceptions or attitudes towards wildlife and conservation (White et al., 2005). A hypothesis test requires a dependent and independent variable(s). Participant attitude is the dependent variable (y) in this research captured in the questionnaire theme "Attitudes of Snow Leopards". The specific questions developed to capture participant attitude has varied in previous studies on large carnivore-human research. For example, Hanson et al., (2019) used two statements to understand respondent attitude: how do you feel about snow leopards, and should snow leopards be present in your area in the future? While Uduman et al., (2021) used a composite score of 8 attitude statements, and Zimmermann et al., (2005) a composite score of 22 attitude statements. Finally, (Carter et al., 2014) employed two bivariate questions (yes/no) to the following statements: do you enjoy having tigers in your area, and would you be happy if no tigers existed in nearby areas? For this questionnaire a summated rating scale was chosen to produce a single composite attitude score based on a series of twelve attitude statements adapted from Zimmermann et al., (2005) and using a similar process to Nepal & Spiteri (2011). A composite score is a common technique used across the social sciences which combines survey data collected on a quantitative continuum into a single variable (Spector, 1992). Responses to the attitude statements were captured on a 3-point scale of agree, neural, and disagree (Likert et al., 1934), including both positive and negative statements (Dunlap et al., 2000). A 3-point scale was selected opposed to a higher point scale due to ease of use and participant understanding in the field, particularly in developing countries (Shaaban, 2019). Various studies have demonstrated that low levels of education and literacy result in respondents unable to discriminate 5-point scales and respond in patterns similar to three-point scales even when five points are used (Chachamovich et al., 2009, Williams & Swanson, 2001). Higher level scales such as 7 or 10 -point have also demonstrated little meaningful distinction between the addition of categories and are comparable when used in regression analysis (Dawes, 2008).

Within each questionnaire theme are the independent variables that may explain attitude towards snow leopards. Potential explanatory variables were determined by reviewing published literature on past attitudinal studies of snow leopard-human conflict (Table 5.2) and guided the creation of each question. Significant varibles in past studies include education, gender, age, agricultural production, total large-bodied livestock holdings, and attitudes towards snow leopard conservation (Hanson et al., 2019; Kusi et al., 2020; Suryawanshi et al., 2014). Additional variables applied in these studies that revealed a relationship, though not significant, were included in the questionnaire design as well due to the unique context of SPNP (Table 5.2). These determinants along with other hypothesized variables from additional studies on large carnivore human conflict (Broekhuis et al., 2020; Endris, 2017; Sibanda et al., 2020; Uduman et al., 2021; Zimmermann et al., 2005) were captured through the questionnaire.

Table 4.2: the relationship between hypothesized predictor variables and attitude towards snow leopards from past studies

Variable	**Relationship**	**Proved Significant?**	**Source**
Education	positive	Yes	(Suryawanshi et al., 2014)
Gender	Males = positive	Yes	(Suryawanshi et al., 2014)

Age	negative	Yes	(Suryawanshi et al., 2014)
Agriculture Production	positive	Yes	(Suryawanshi et al., 2014)
Non-Buddhist	positive	Not in regression, but yes in bivariate	(Hanson et al., 2019)
Less than very religious	positive	Not in regression, but yes in bivariate	(Hanson et al., 2019)
Non-native	positive	Not in regression, but yes in bivariate	(Hanson et al., 2019)
Sustainable Livelihood Index Score	positive	Not in regression, but yes in bivariate	(Hanson et al., 2019)
# Of large-bodied livestock	negative	Yes	(Suryawanshi et al., 2014)
Proportion of large-bodied livestock killed by snow leopard	Negative (Kusi) No relationship (Suryawanshi)	No	(Kusi et al., 2020; Suryawanshi et al., 2014)
Could identify snow leopard via photo	positive	Not in regression, but yes in bivariate	(Hanson et al., 2019)
Attitude towards snow leopard conservation	positive	Yes	(Hanson et al., 2019)

The literature review was then used to develop the hypothesized relationship between attitude towards snow leopards and variety of independent variables captured in the questionnaire (Table 5.3).

Table 4.3: Hypothesized relationship between independent variables and attitude towards snow leopards

Independent Variable	Hypothesized Relationship
Age	Negative
Education	Positive
Gender	Males = Positive
Primary Income Source	Herding = negative, Tourism = Positive
Total Livestock Holdings	Negative
Total Livestock Killed by Snow Leopard	Negative
Number of external supports received	Positive
Attitude towards snow leopard conservation	Positive
Observed change in external supports provided by various conservation / government groups	Positive
Region	Upper Dolpo = Positive

The questionnaire was written in English and conducted verbally in Dolpo, the local language spoken by residents of SPNP also referred to as Phoke Dolpa, Dolpa Tibetan, Dolpike, and Dölpo. Two research assistants were required to conduct the questionnaire who are fluent in both English and Dolpo. To ensure that the questions in English would translate well into Dolpo while considering local vernacular, the questionnaire was pre-tested in Kathmandu by the two research assistants. Each research assistant is from the Dolpo district and specifically

Shey Phoksundo National Park, with extensive experience conducting past research in SPNP, knowledge of local vernacular, and guidance on how to word questions so community members would understand while staying true to the questions. In addition, if any information arose that went beyond the scope of the survey, then the research assistants would translate that to English and I would record the information. After the pre-tests in Kathmandu the following questions were altered for greater clarity:

Table 4.4: the steps taken to alter survey questions following a pre-test in Kathmandu.

Question	Alteration	Reasoning
1.2.4	Addition of livestock category: Hybrid (Tolbo, Tolmo, Dzo, Dzomu)	Addition of livestock category for hybrid species that would not fit into initial categories
3.1	3.1 How do you feel about the following statements? Altered from a 5-point Likert-scale to a 3-point Likert scale.	Reduction from a 5 point Likert scale to a 3 point because respondents would have a hard time distinguishing between categories (e.g. strongly agree and agree)
5.1	5.1 How do you feel about the following snow leopard conservation strategies? Altered from a 5-point Likert scale to a 3-point Likert scale.	Reduction from a 5-point Likert scale to a 3-point because respondents would have a hard time distinguishing between categories (e.g., strongly agree vs. agree)
6.7	What percentage of your household income comes	The addition of the “Yartsa” category to sources of household income. This was not

	from the following sources: Addition of the Yartsa category	previously identified as an income source until the pre-test.

The questionnaire was conducted on paper at the location most convenient for the respondent. First, verbal consent was acquired and recorded before proceeding with the questionnaire. Each respondent was told that they could stop at any point if they no longer wished to answer or skip a given question. To reduce the chance for exaggeration, particularly in areas such as number of livestock killed by snow leopards, each respondent was told that their response would be anonymous (Uduman, 2019). Responses to each question were recorded by hand in English on the questionnaire form, and later coded and recorded in Excel.

4.2.3 Attitude towards snow leopards

One of the themes in our questionnaire was attitude towards snow leopards. Within this theme, I used the responses to questions 3.1.1 – 3.1.12 (Appendix B) to investigate our first research question: what are the attitudes of local communities towards snow leopards in SPNP? To answer this question for the park as a whole, I summarized the responses of each attitude statement by the total responses within each category (agree, neutral, or disagree) for a given question. This percent was calculated by dividing the count of responses within each response category by the total sample size (n = 105) for each attitude statement. This process was repeated for each of the twelve attitude statements.

I then answered the above question at the scale of region. As mentioned, various factors in livestock holdings, accessibility, and snow leopard density vary between the two regions and anticipated differences to arise between attitude statements. I split the attitude responses into two groups based on village location. This resulted in two regions that could now be investigated to determine if significant differences in attitude responses exist using a Chi-squared test for independence. A Chi-squared test for independence is a non-parametric test that can be used to compare nominal or ordinal data (Mchugh, 2013). This test asks if there is a statistical difference between the observed and expected values (Hess & Hess, 2017). The null hypothesis for the purpose of this research is that attitude response and region are independent of one another. The alternative hypothesis is that there is a relationship between attitude response and region. While all the assumptions of a Chi-squared test were met for most of the attitude statements, the assumption that the expected values should be > 5 (Mchugh, 2013) was not met for 3.1.1, 3.1.2, 3.1.5, 3.1.8, and 3.1.11. For these statements, a Fisher's exact test was used in its place. A Fisher's exact test is typically used for small sample sizes and asks what the probability is of getting data that is more extreme than the observed values, and the p-values are comparable to the Chi-square test (Hess & Hess, 2017). Both these tests were conducted to compare attitude statement responses by region.

4.2.4 Determinants of Attitude: General Linear Models

The second research question asks what are the potential drivers of attitude towards snow leopards. I approach this question with the desire to explain attitude scores rather than predict attitude scores. To answer this question a composite attitude score was developed for each respondent. The first step in the development of this composite score was to test for internal consistency amongst the twelve attitude statements. Internal consistency can be examined using Cronbach's alpha. Cronbach's alpha can examine whether all the items in a composite score measure the same variable – in this case attitude towards snow leopards – which has been used in many other cases of carnivore human conflict (Endris, 2017; Uduman et al., 2021). When comparing a composite score between groups, a Cronbach's Alpha score > 0.7 is considered satisfactory (Bland et al., 1997). Of the twelve attitude statements included in the questionnaire, two were removed prior to conducting the alpha score and subsequent composite attitude score. 3.1.10 was removed as it proved a neutral statement and subsequent scoring was not possible. 3.1.11 was removed as it showed to have no variance in response. These two statements were removed from further analysis. The final Cronbach's alpha score (n = 105) with the remaining 10 statements is 0.71 using a 95% confidence internal. This is considered an acceptable level of internal reliability, especially considering the small sample size.

The next step was to determine the composite attitude score for each respondent. This was calculated by coding the 10 remaining attitude statements. A positive statement such as "snow leopards deserve protection" was coded as follows: agree = +1, neutral = 0, and disagree = -1. Negative statements used reverse coding. For example, a negative statement such as "I would be happier with fewer snow leopards in Shey Phoksundo National Park" was coded as follows: agree = -1, neutral = 0, and disagree = +1. This allows for the summation of the 10 remaining attitude statements with a composite score ranging from +10 to -10, where a score of +10 indicates an extremely positive attitude and -10 indicates an extremely negative attitude. Our scale included an “unsure” category. The purpose of this category was to allow respondents to refrain from answering a question if they so desired. Certain questions resulted in more unsure responses than others, such as “If someone loses their livestock in a mass killing, it is okay for them to kill the snow leopard” which had 19% of responses select this category. Because the “unsure” category is not ordinal data and cannot be used in subsequent analysis, a respondent that answered unsure to any of the above 10 attitude statements was removed from further analysis. This reduced our total sample size (n = 59). This decision was made firstly due to the large number of individuals that selected this category an averaging would skew the remaining results, and secondly because it is not truly “missing” data. This reduced sample size was used for all analysis moving forward.

A second composite attitude score was then developed for the independent variable of “attitude towards snow leopard conservation”. The above process was repeated for this independent variable. This score was calculated from combing the ordinal responses to survey questions 5.1 and 5.2 (Appendix A). First, the internal consistency for the 13 questions was examined to test internal reliability (n = 105). When all 13 statements were used together, the Cronbach Alpha score was 0.54. While composite scores for the variable “attitude towards conservation” have proved adequate in the past (Hanson et al., 2019), and scores between 0.6 and 0.7 have been used (Uduman, 2019), the nature of this score was too low to be considered internally reliable. This meant removal of this variable from future analysis. Next, the internal reliability was examined for 5.1 and 5.2 independently. The Cronbach alpha score for 5.1 was 0.34, which is a very poor score and thus not deemed internally reliable. However, the score for 5.2 was

0.80. This is an acceptable level of internal reliability indicating that the three statements in question 5.2 are measuring the same latent variable. The composite score for question 5.2 was created for each respondent ranging from -3 indicating a very negative attitude to +3 indicating a very positive attitude. If a respondent answered “unsure” they were assigned a missing value for this score following the procedures from the composite attitude score. Of the 59 composite scores, 9 were missing this score due to selecting “unsure” for one of these responses. This new composite score was titled “observed change in external supports” as this more adequately captures the nature of the questions in 5.2 and was used in future analysis.

I examined collinearity before running the multiple regression analysis. The relationship between each independent variable and the dependent variable (composite attitude score) was examined. Those that proved a significant relationship were included as potential predictor variables in the subsequent regression model. Next, the collinearity between these significant continuous and ordinal independent variables was examined using the Polycor package in R (J. Fox 2016) using a Pearson’s correlation coefficients were used. If two predictor variables had a correlation > 0.5, one predictor variable was removed. No significant correlation was observed. The correlation between the significant categorical independent variable (region) and continuous independent variables was examined using t-tests. This was selected because region is a binary variable. No significant correlations were observed.

Next, I conducted the multiple regression analysis. I used Akaike’s Information Criterion to rank the performance of candidate models, after being corrected for small sample size (AICc). AIC values are often used in explanatory rather than predictive models. For example, they are used often in behavioral ecology when a range of variables are being explored for their association with a given trait (Symonds & Moussalli, 2011), and have been used for model selection in similar human-wildlife conflict analysis (Broekhuis et al., 2020; Goljani Amirkhiz et al., 2018; Uduman et al., 2021).

Multiple linear regression was used with a best-subsets selection process which produced all candidate models for each additional of another independent variables. The best model was determined through the selection of the model with the lowest AICc value. Any model which produced an AICc value within 3 units of the best model were considered as plausible models. In addition, a forward, backward, and mixed stepwise regression was conducted to compare if the final model selection differed between the varied approaches.

4.3 Results

First, general respondent characteristics and summary statistics on themes including snow leopards, livestock depredation, and mitigation strategies are reported. Second, attitudes towards snow leopards are presented for the park as a whole, then split between Lower and Upper Dolpo. Attitudes towards snow leopards proved to vary significantly in certain areas between Lower and Upper Dolpo. Third, the drivers of attitude are examined using a variety of predicator variables captured in the quantitative questionnaire including a presentation of the best explanatory model for composite attitude score.

4.3.1 Respondent Characteristics

Table 4.5: Personal characteristics of respondents split between Lower Dolpo (n = 60) and Upper Dolpo (n = 45).

Characteristic	**Lower Dolpo**	**Upper Dolpo**
Male (%)	48	40
Age (%):		
18 – 24	2	16
25 - 44	45	33
45 – 64	43	40
65 >	10	11
Education (%):		
0 (yrs)	75.9	81.4
1 – 4 (yrs)	3.4	4.7
5 – 8 (yrs)	10.3	4.7
9 – 12 (yrs)	10.3	9.3
Primary Income Source (%)		
Herding	20.4	65.0
Tourism	16.7	5.0
Agriculture	9.3	12.5
Yartsa Collection	44.4	10.0
Other	9.3	7.5
Livestock Holdings (avg / household)		
Goats & Sheep	11.1	54.0
Yak, Horse, Cow, Hybrid	15.6	9.8
Total	26.7	63.8

Similarities and differences exist between the individuals who completed the questionnaire in Lower versus Upper Dolpo (Table 4.4). Less than half of the individuals (48% and 40%) who completed the questionnaire were male for both regions. The age distribution of responses is roughly the same as well, where Upper Dolpo has slightly more young adults (16%) than Lower Dolpo (2%). Most respondents fell between the age range of 25 – 64 for both regions. Years of education completed are similar with three quarters of responses for Lower and Upper Dolpo (76% and 81%) had not completed any years of schooling. Differences appear when looking at primary income source. In Lower Dolpo the most common primary income source was Yartsa (44%), in Upper Dolpo the most common primary means of income was herding (65%). A Fisher's exact test determined a significant relationship exists between primary income source and region ($p = 3.114e-05$). Number of livestock also varies between regions. A household in Lower Dolpo has on average 27 livestock, with the majority being large bodied such as yak, horse, cattle, or a hybrid. A household in Upper Dolpo has on average 64 livestock, with the majority being small bodied such as goats and sheep. A two-sample unpaired t-test was performed to compare total livestock holdings between Lower and Upper Dolpo. Prior to this test total livestock holdings was transformed using log10 to fit a normal distribution (Shapiro-Wilk normality test $p > 0.05$). There was a significant difference in the log of total livestock holdings between lower Dolpo ($M = 1.25$, $SD = 0.43$) and Upper Dolpo ($M = 1.54$, $SD = 0.56$); $t(80) = -2.96$, $p = 0.0041$.

4.3.2 Summary Statistics: Snow Leopards and Livestock Depredation

Respondents (n=105) were asked a variety of questions surrounding their knowledge of snow leopards. Most people had seen snow leopard over the past 5 years (79%). When asked if they see more or fewer snow leopards now than 5 years ago, the majority of people responded with seeing more snow leopards now than 5 years ago (78%).

Most households have experienced livestock depredation by snow leopards at some point over the past 5 years (93%). The total number of reported livestock killed by snow leopards for all respondents was 719 over the past 3 years (mean = 2.3 livestock lost/household/yr.). A Kruskal-Wallis test was used to examine the difference for livestock killed between Lower and Upper Dolpo. Kruskal-Wallis test was chosen due to the non-normal distribution of livestock killed, as even after a log10 was applied the distribution remained non-normal. There was a significant difference in the livestock lost between Lower Dolpo ($M = 3.62$, $SD = 6.51$) and Upper Dolpo ($M = 11.16$, $SD = 12,03$); Kruskal-Wallis chi-squared = 22.76 ($p = 1.84e-06$). As a method of knowledge validation, the respondents were asked the open-ended question of how they knew their livestock had been killed by a snow leopards opposed to other carnivores in the area such as wolves. The most common response cited bite marks on the neck or throat area (76%). Additional responses included pugmarks, vultures circling, blood sucked, and stomach hole. When asked if the respondent thought more of their livestock were being killed by snow leopards now than 5 years ago, two thirds of the responses (66%) indicated more livestock killed now. The sensitive topic of retaliatory killings was discussed by asking if they had heard of someone killing snow leopards over the past 5 years. Half of the responses indicated no (49%), and the remainder was evenly split between yes (29%) and unsure (22%).

A variety of questions asked respondents who they report to after one of their livestock has been killed by a snow leopard. The majority of respondents report to park authorities (70%), and slightly more report to the Snow Leopard Conservation Committee (75%). In terms of strategies that the respondents had used to date to protect their livestock, most had tried increased human presence (90%), followed by relocating livestock (75%), then guarding dogs (50%), and lastly predator proof night corrals (3%). The percent total for strategies used surpasses 100% because a respondent could use multiple techniques. When asked the factors stopping them from applying additional mitigation strategies, the most common response was education (67%) followed by cost (60%).

4.3.3 Attitudes Towards Snow Leopards

When looking at the park as a whole, there is an overall positive attitude towards snow leopards (Table 4.5). When asked if the nature and wildlife in SPNP is a global treasure and should be conserved, the majority of people agreed (83% and 79% respectively). Three statements were used to capture perceptions of livestock depredation in relation to snow leopards. The first is if snow leopards killing livestock is an acceptable risk to herding, in which the majority (75%) agree with this statement. The second states I cannot tolerate snow leopards killing a single livestock, in which most people respond positively with disagree (33%) or neutral (20%). The third states if someone loses their livestock in a mass killing, it is okay to kill a snow leopard, responses were evenly split between disagree (30%) and neutral (37%). Three questions address the desire to implement solutions and work with park authorities. An overwhelming number of responses indicate they would implement solutions if only they knew how (96%), that mass killing is a problem local authorities need to address (75%), and that they would be willing to work with park authorities (75%). The two questions that target the potential benefits that snow leopards could bring to their households have more negative responses. Roughly half of the responses indicate that their livelihoods are more important than snow leopards (47%), and that snow leopards do not provide benefits to their household (55%). Finally, two questions target conservation of snow leopards. Over half of the responses (57%) indicate they disagree with the statement "they would be happier with zero snow leopards in SPNP in the future". Lastly, a majority of people responded positively (63%) that snow leopards deserve protection.

Table 4.6: Responses to the twelve snow leopard attitude statements (n = 105). Responses were given on a 3-point scale, with the additional unsure category. Row totals equal 100%.

Question	**Agree (%)**	**Neutral (%)**	**Disagree (%)**	**Unsure (%)**
3.1.1 The nature and wildlife in Shey Phoksundo is a global treasure	83	10	4	4
3.1.2 The nature and wildlife in Shey Phoksundo should be conserved	79	11	5	5
3.1.3 If someone loses their livestock in a mass killing, it is okay for them to kill the snow leopard	13	37	31	19
3.1.4 Snow leopards provide benefits to my household	21	20	55	4

3.1.5 My livelihood is more important than snow leopards	47	34	5	14
3.1.6 In this household, we cannot tolerate snow leopards killing a single livestock	36	20	33	10
3.1.7 I would be happier if zero snow leopards lived in Shey Phoksundo in the future	23	16	57	4
3.1.8 Snow leopards killing livestock is an acceptable risk to herding (if it is not mass killing)	75	10	10	5
3.1.9 Snow leopards mass killing livestock is a problem that local authorities need to address	75	10	2	12
3.1.10 I would want to implement solutions to livestock killings by snow leopards if I knew how	96	0	0	4
3.1.11 I would be willing to work with authorities to implement solutions to protect snow leopards	77	11	3	9
3.1.12 Snow leopards deserve protection	62	18	15	5

The attitude statements were then divided to examine the views between those residing in Lower Dolpo to those residing in Upper Dolpo. Those who reside in Lower Dolpo have a more positive attitude towards snow leopards than those in Upper Dolpo. This difference can be seen most significantly ($p < 0.000$, Cramer's $V = 0.55$) in the attitude statement "I would be happier if zero snow leopards lived in Shey Phoksundo in the future". Most people living in Lower Dolpo disagree with this statement (78%), whereas less than a third of people living in Upper Dolpo disagree (29%). Similar significant results ($p < 0.000$, Cramer's $V = 0.43$) occurred with the statement "snow leopards deserve protection", were most people in Lower Dolpo agreed (80%), whereas only a third of people in Upper Dolpo agreed (38%). Other significant differences include "snow leopards killing livestock is an acceptable risk to herding" ($p<0.000$, Cramer's v = 0.46), and "the nature and wildlife in Shey Phoksundo should be conserved" (p = 0.001, Cramer's V = 3.7). In both cases those in Lower Dolpo (92%, 92%) agreed with the statements whereas less respondents agreed (53%, 62%) in Upper Dolpo.

Table 4.7: Responses to snow leopard attitude statements divided by Lower Dolpo (n = 60) and Upper Dolpo (n = 45). Responses were given on a 3-point Likert scale. Significance tests are reported including Chi-squared tests for independence (or Fishers Exact test if at least one expected frequency was < 5), and strength of the relationships using Crammer's V (where values range from 0 to 1 where 1 is a perfect association). "Unsure" was excluded from the analysis and accounts for the difference between row totals and 100. * Indicates statistical significance.

Attitude Statement	Agree		Neutral		Disagree		Statistics		
	L	U	L	U	L	U	X^2	*P*	*Cramer's V*
3.1.1 The nature and wildlife in Shey Phoksundo is a global treasure	92	71	3	18	2	7	n/a	0.009*	0.293
3.1.2 The nature and wildlife in Shey Phoksundo should be conserved	92	62	3	22	2	9	n/a	0.001*	0.370
3.1.3 If someone loses their livestock in a mass killing, it is okay for them to kill the snow leopard	12	16	32	44	35	24	2.223	0.329	0.162
3.1.4 Snow leopards provide benefits to my household	30	9	20	20	45	69	8.074	0.018*	0.283
3.1.5 My livelihood is more important than snow leopards	43	51	35	33	5	4	n/a	0.883	0.055
3.1.6 In this household, we cannot tolerate snow leopards killing a single livestock	32	42	23	16	32	36	1.544	0.462	0.128

3.1.7 I would be happier if zero snow leopards lived in Shey Phoksundo in the future	13	36	3	33	78	29	30.710	0.000*	0.551
3.1.8 Snow leopards killing livestock is an acceptable risk to herding (if it is not mass killing)	92	53	3	18	2	22	n/a	0.000*	0.459
3.1.9 Snow leopards mass killing livestock is a problem that local authorities need to address	78	71	8	13	2	2	9.427	0.009*	0.288
3.1.11 I would be willing to work with authorities to implement solutions to protect snow leopards	82	71	10	13	2	4	n/a	0.578	0.115
3.1.12 Snow leopards deserve protection	80	38	10	29	7	27	19.298	0.000*	0.439

4.3.4 Determinants of Attitude

A composite score was created for each respondent and was used as the dependent variable in this analysis. Values from the composite attitude scores could range from a perfectly negative score (-10) to a perfectly positive score (+10). The actual values from the sample after removing those who selected "unsure" (n = 59) for the composite scores ranged from -4 (negative) to +10 (very positive) with a mean score of 3.71 and a standard deviation of 3.59.

Simple linear regression was used to examine the relationships between composite attitude score and each of our potential attitude predictor variables independently. This was done to prior to multiple regression modelling to identify which variables held a meaningful relationship with attitude. No significant relationship existed between the composite scores and the total livestock holdings, livestock killed over the past 3 years, age, gender, and primary income source. However, some relationships did prove significant. A simple linear regression was used to test if observed change in external supports significantly related to attitude to snow leopards. The fitted regression model was: 3.410 +1.043. The overall regression was statistically significant (Adjusted $R^2 = 0.280$, $F(1, 48) = 20.03$, $p = 4.692e-5$). This technique was also used to test if region significantly predicted composite attitude scores. Prior to running the regression region was dummy coded where Lower Dolpo = 1 and Upper Dolpo = 0. The fitted regression model was: 1.90 + 3.57(Lower Dolpo). The overall regression was statistically significant (Adjusted R2 = 0.24, F(1,57) = 19.19, p = 5.124e-05). The relationship between composite attitude score and the number of external supports a respondent had benefited from (such as relief, livelihood development, etc.) also proved significant. The fitted regression model was: 2.13 + 1.42. The overall regression was statistically significant (Adjusted R2 = 0.15, F(1, 57) = 11.43, p = 0.00131). Lastly, years of education was used to test if region significantly predicted composite attitude scores. The fitted regression model was: 2.93 + 0.29. The overall regression was statistically significant (Adjusted R2 = 0.11, F (1,57) = 8.22, p = 0.00579).

Next, a multiple linear regression was used to examine the relationship between the composite attitude scores and the combination of significant predictor variables to determine if any model could better explain composite scores than a single independent variable alone. Some additional predictors were included that did not meet the above significance test but proved significant in other studies such as gender, age, and total livestock holdings (Kusi et al., 2020; Suryawanshi et al., 2014). This resulted in a total of 7 potential independent variables (region, education, count of external supports received, observed change in external supports, gender, age, and total livestock holdings). All possible models were examined using a best subset technique selecting the top 4 models with each addition of an independent variable. The top performing models are reported (Table 4.7). Models shown are within 3 AICc units of the model with the lowest AICc value.

Table 4.8: Predictor variables included in general linear models to identify determinants of pastoralists attitudes (n=59) toward snow leopards in SPNP. Models shown are those that were within 3 AICc units of the candidate model with the lowest AICc. Additional measures of model ranking are included such as Df (n-k-1), R2, RMSE, BIC, and CP. Models ordered from lowest AICc to highest AICc.

Model	**df**	**AICc**	**BIC**	**R2**	**RMSE**	**CP**
Region + Gender + Education + Count of External Support + Observed Change in External Support	53	243.569	254.287	0.584	2.494	4.454
Region + Education + Count of External Support + Observed Change in External Support	54	245.646	255.165	0.5417	2.587	6.722
Region + Age + Gender + Education + Count of External Support + Observed Change in External Support	52	246.261	258.045	0.585	2.519	6.324
Region + Total Livestock + Education + Count of External	52	246.339	258.123	0.584	2.521	8.716

Support + Observed Change in External Support						

The best performing model included the independent variables of region, gender, years of education, count of external supports received, and observed change in external supports. This model proved to have both the lowest AICc and BIC values. All the covariates in the top performing model were statistically significant at a confidence interval of 0.05. There is a positive relationship between composite attitude score and years of education (0.194, 95% CI, P = 0.011), gender (0.948, 95% CI, P = 0.041), number of external supports received (0.658, 95% CI, p = 0.049), and observed change in external supports (1.093, 95% CI, p = 0.008). In other words, this reveals that a respondent is more likely to have a positive attitude towards snow leopards if they have more years of education, are male, have received more external supports, and have observed a more positive change in external supports. There is a negative relationship between region (Upper Dolpo) and composite attitude score (-1.04, 95% CI, p = 0.003). In other words, if an individual lives in Upper Dolpo they are more likely to hold a more negative attitude towards snow leopards that if they lived in Lower Dolpo.

R^2, RMSE, BIC and CP are additional criteria to rank the performance of candidate models often emphasized in predictive rather than explanatory models but are still important to consider. Mallow's CP addressed multicollinearity between predictor variables as a measure of the degree of bias in a model, with the lower the number the less bias present (Zuccaro, 1992). The model with the lowest AICc also presents the lowest CP value. R^2 is a measure of the goodness of fit of a given model. Where AICc is a relative measure that will always produce the "best" model with the lowest AICc compared to other models, it does not address the goodness of fit of the model that an R^2 value can (Symonds & Moussalli, 2011). While the R^2 is higher for our third model with the addition of the variable "age", this could be subject to overfitting as the addition of "age" does not significantly impact the R^2 score. Root Mean Squared Error (RMSE) is usually reported in conjunction with R^2. RMSE is the standard deviation of the residuals, which measures how spread-out residuals are, with the model presenting the lowest RMSE value being selected as best (Kalbi et al., 2018). The model with the lowest AICc value also holds the lowest RMSE value. Bayesian information criterion (BIC) is another model criteria rank where the model with the lowest BIC value is selected (Burnham & Anderson, 2004). The top performing model with the lowest AICc also presents the lowest BIC value. In addition, I conducted a forward, backward, and mixed stepwise selection process with a p-value threshold of 0.05, and all three resulted in the selection of the same model with the lowest AICc value above (region + gender + education + count of external supports received + observed change in external supports). The addition of age and total livestock holdings in the forward selection did not meet the criteria of p-value threshold of 0.05, nor the removal threshold of 0.05 in backward selection.

4.4 Discussion

4.4.1 Local Attitude Towards Snow Leopards

Snow leopards and local communities have a long-shared history in Shey Phoksundo National Park. Most respondents revealed an increasing trend in both the number of snow leopards they have seen, and the number of their livestock being lost to snow leopard depredation. Despite this, when looking at our study extent as a whole there is an overall positive attitude towards snow leopards. Most people believe that Shey Phoksundo National Park is global treasure that should be conserved, and that the snow leopard deserves protection. Thesis findings share similarity with research in the past that has indicated a more positive attitude towards snow leopards in neighboring Annapurna. While studies from 30 years ago indicated only 4% of respondents holding a positive view towards snow leopards (Oli et al., 1994), more recent studies indicate a more positive attitude of up to 60% holding a positive view (Hanson et al., 2019). When examining attitudes towards livestock depredation by snow leopards, our study shows that most respondents believe that this loss is an acceptable risk to herding, but that mass killing is a problem that local authorities need to address. This demonstrates that individuals look more negatively upon mass killing events, and rightly so, as the financial loss in one of these events is extremely large.

Despite the proximity of Lower and Upper Dolpo, our study highlighted differences between the two regions. In terms of respondent characteristics, Lower Dolpo proved to have more large-bodied livestock such as yak and horse, a primary income source of Yartsa, and an average livestock holding of 27 animals per household. Upper Dolpo proved to have more small bodied livestock such as goats and sheep, a primary income source of herding, and an average livestock holding of 63 animals per household. Other studies have found similar trends in SPNP, where Upper Dolpo has more small, bodied livestock, more livestock per household, and more instances of depredation (Khanal et al., 2020) Another study in Upper Dolpo identified agropastoralism as the primary livelihood (Kusi et al., 2020) which matches with our study. With these known differences, it is perhaps no surprise that there are differences in attitudes towards snow leopards between these two regions. Upper Dolpo demonstrated more negative attitudes than Lower Dolpo. This difference might be most clearly demonstrated in the significant difference between the regions and the statement that snow leopards deserve protection, or the significant difference between the statements snow leopards killing livestock is an acceptable risk to herding.

4.4.2 Determinants of Attitudes

Our study found that the combination of region, gender, education, number of external supports received, and the perception of change in external supports were the variables that best explain attitude towards snow leopards.

As discussed in early sections the region that a respondent is located relates to their attitude towards snow leopards, with those in Upper Dolpo holding more negative attitudes than those in Lower Dolpo. Our study found that men hold more positive views than woman towards snow leopards, which is similar to other snow leopard attitude studies (Kusi et al., 2020; Suryawanshi et al., 2014). These findings could be due to the role women often take in this region as herders, and perhaps more likely to directly come in contact with the snow leopard or the negative impacts of livestock depredation. I also found that years of education had a significant positive relationship with attitude towards snow leopards similar to another snow leopard attitude study (Hanson et al., 2019; Suryawanshi et al., 2014). The greater the years of education, the more likely an individual with hold a positive view towards snow leopards. Many other studies on attitudes towards large carnivores have demonstrated the importance of education and its relationship towards attitude (sources).

The observed change by a respondent on the number of external supports provided by their local snow leopard conservation committee, local government, and local NGOs was the most influential factor to explain attitudes. This finding is similar to a study by Hanson et al., (2019), who found that attitude towards snow leopard conservation as the factor that best explains attitude towards snow leopards. Our findings highlight the importance of local community perception of entities that are actively working towards snow leopard conservation. The number of external supports an individual had received also proved a significant explanatory factor in attitude. Combined, these two factors demonstrate the importance of both the number and perception of external supports in explaining their attitude towards snow leopards.

A number of explanatory variables were hypothesized to influence attitude but in fact did not prove significant. Our study found no relationship between the number of livestock owned or the number of livestock lost to snow leopard depredation, and attitude towards snow leopards. This relationship has offered mixed results in similar studies, with a similar non-relationship observed in three regions in Nepal (Kusi et al., 2020), however number of livestock owned proved significant in Annapurna (Hanson et al., 2019). These findings demonstrate the complex relationship between livestock depredation and attitude. Perhaps for our study area, this non-relationship could suggest that strategies targeted solely at reducing the number of livestock killed may not improve the attitude of local communities towards snow leopards. Age was another variable that did not appear in our top performing model and when examined independently had no significant relationship towards attitude. Other studies have identified a negative relationship between age and attitude towards snow leopards (Suryawanshi et al., 2014). Lastly, primary occupation did not prove to significantly influence attitude towards snow leopards. I had hypothesized that those who relied on herding for their primary income would hold more negative views, while those who rely on tourism would be more positive based on other studies. For example, in India, those respondents who participated in a tourism homestay program held a more positive view of snow leopards (Vannelli et al., 2019). This demonstrates that tourism could act as a bridge to between local perceptions of snow leopards and economic revenue.

4.4.3 Pathways to Coexistence

Our research on local attitudes towards snow leopards and determinants of these attitudes can guide future pathways to coexistence. How conservation of snow leopards is perceived by the local community is an important aspect of coexistence (Hanson et al., 2019).. Local ecological knowledge has been used in conjunction with spatial analysis in coastal communities in Louisiana to identify how this knowledge can be transformed spatially to guide management decision of coastal restoration (Bethel et al., 2014). Education and awareness could reduce negative attitudes towards snow leopards and retaliatory killings (Hanson et al., 2019). In particular, our study demonstrated that education was the most significant barrier to the implementation of additional livestock husbandry measures to protect livestock. Ialso identified that women hold more negative views of snow leopards than men. These two findings could be used together to generation an education campaign that empowers and teaches women additional ways to conserve their livestock.

While the number of livestock killed by snow leopards did not prove a significant driver of attitude, three quarters of our respondents identified mass killings as a problem local authorities need to address. With mass killings occurring in locally crafted traditional night corrals, the core of this pathways is the creation of predator proof night corrals. Though their effectiveness has not been broadly researched, night corrals have proven effective in some case studies around the world by protecting livestock from large carnivores (Frank et al., 2005; Breitenmoser et al., 2005). In the context of the snow leopard, one study suggested that for each predator proof corral installed in a community up to five snow leopards are saved from retaliatory killings (R. M. Jackson & Wangchuk, 2004). Those numbers make this an appealing solution to mitigate snow leopard – human conflict but this strategy has drawbacks. The construction of night corrals in low suitability habitat may negatively impact snow leopard survival through food source elimination (Bagchi, 2019). In addition, economic support for corral construction would be required as the night corrals were found to cost between $400 and $800 USD (R. M. Jackson & Wangchuk, 2004). This number could be higher for more remote communities such as those living in Shey Phoksundo National Park as materials may need to travel long distances. Our study did identify that cost was the second highest barrier for a respondent to adopt additional mitigation strategies, a barrier which would need to be addressed moving forward.

A final group of strategies target the economic loss felt by herders when their livestock are killed by snow leopards or the economic gain that they would experience from snow leopards living in SPNP. Our study identified that over half of the respondents do not see any benefits from snow leopards to their household. Pastoralism is a crucial livelihood strategy for remote communities (Lute et al., 2018) such as those living in the high mountainous regions of Nepal. Alternative income strategies that result in greater financial security have been shown to increase local communities' tolerance of snow leopards in India (Bagchi & Mishra, 2006). Ecotourism is a common strategy proposed in snow leopard habitat to diversify local livelihoods. India in specific has conducted recent studies on the economic benefit to local communities from tourism present in their protected areas. A wide range of tourism income reported by community members in Hemis National Park, ranging from $123 - $6152 (Maheshwari & Sathyakumar, 2019). Ladakh India implemented the Himalayan Homestay Program, and recent research on the program revealed that those community members that participated in the program benefited more than those who did not from tourism revenue and held a more positive view of snow leopards (Vannelli et al., 2019). This demonstrates that tourism may act as a bridge to between local perceptions of snow leopards and economic revenue. Also, the community in Ladakh reported an overall positive outlook on tourism in the area and a desire for it to increase in the future (Vannelli et al., 2019). This research suggests that tourism could be a potential strategy to diversify the income of local communities for the case of Shey Phoksundo National Park. But this strategy is not without challenges, as the remote location of the park and little infrastructure development would need to be addressed to cater to international visitors. The making of handicrafts is another revenue stream used to diversity livelihoods in regions of snow leopard – human conflict. This strategy is in use by pastoralist families in Mongolia, who were able to increase their yearly income by 25% through the making of handicrafts from the wool their sheep produced (Mishra et al., 2003b). The challenge with this strategy is the ability to access global markets that would purchase the handicrafts. Mongolia tackled this problem through the creation of a company by the name of Snow Leopard Enterprises. The company was established to increase access to global markets and agreed to buy a set number of handicrafts each year if the community members agreed to snow leopard conservation initiatives in the region (Mishra et al., 2003b)With this in mind, regions that have higher proportions of sheep as livestock would benefit most from this strategy. Our study identified that Upper Dolpo residents have more sheep and goats, and also more negative attitudes. A handicraft pilot project could be implemented to diversity the livelihoods of individuals in this region.

Livestock insurance programs are the final strategy proposed to alleviate the economic burden of livestock depredation. An incentive program was piloted in the Spiti Valley in India where herders contributed a premium to the insurance program that would provide up to 100% compensation for the livestock killed by snow leopards (Mishra et al., 2003b). An update on programs like the one in Spiti would be beneficial to snow leopard conservation as they could determine if local attitudes improved over time with insurance schemes, and if herders were better off economically with the insurance program in place. Regions of conflict between wolves and shepherds in Italy conducted this form of research concluded that the compensation schemes in place for twenty years did not result in increased shepherd tolerance of wolves (Marino et al., 2016). This could be because the scheme was not implemented as a participatory strategy, but rather a top down strategy placed upon shepherds where only half chose to partake in the program all together (Marino et al., 2016). If a livestock insurance program was to be put in place in Shey Phoksundo National Park, it would need to be discussed with villagers before hand to determine the best implementation method, funding amount, and requirements on how to prove that livestock was in fact killed by snow leopards. Our study did ask respondents if they would be willing to contribute to an insurance program. An overwhelming majority said they would, indicating this as a viable solution.

4.5 Conclusion

Pastoralist communities have lived with snow leopards for generations and their perceptions and attitudes should be at the forefront of conflict research. While social science research often lags behind the natural sciences in human-wildlife conflict studies, this research offers an understanding of local attitudes towards snow leopards in Shey Phoksundo National Park. As a whole the attitudes towards conservation and the snow leopards are positive. However, when split between region, Upper Dolpo proves to hold more negative attitudes towards snow leopards that Lower Dolpo. I explored what variables proved to best explain these attitudes towards snow leopards. This analysis revealed five significant drivers: gender, years of education, region, number of external supports received, and perception of change in external supports. This research can be used to guide future pathways to coexistence that are already underway in Shey Phoksundo National Park. Education on mitigation strategies that individuals can implement themselves could lead to more positive attitudes. Initiatives could be targeted to women and made more accessible to individuals with less years of education. Locals show a tolerance to a few livestock killed by snow leopards, but the continued implementation of predator proof night corrals is needed to address the perception that local authorities need to help reduce mass killing events. Additional livelihood strategies such as tourism or handicrafts could be implemented so that local communities perceive greater benefits from the presence of snow leopards in SPNP. Lastly, most individuals indicated that they would contribute to an insurance scheme which could now be implemented in these areas. I believe that this understanding of local perceptions and pathways can offer greater coexistence between communities and snow leopards.

Chapter 5: Current and Future Conflict Resolution Efforts in SPNP

Conflict resolution strategies that are able to foster coexistence between communities and snow leopards are ones that are able to simultaneously address biological conservation with economic development. As our understanding of this complex socio-ecological system grows the challenge now becomes how to apply this knowledge for successful coexistence. It would be naive to think that a single strategy will create immediate and harmonious coexistence anywhere in Nepal. Moreover, what works and what does not is likely to vary from one local context to the next. With this being said, a variety of solutions have been proposed across Asia to address snow-leopard human conflict for both biodiversity conservation and economic development. Such strategies are diverse in nature and look to address actors from the snow leopard to wild prey, and from livestock to communities (table 5.1).

Table 5.1: Snow leopard mitigation strategies suggested across Asia.

Strategy	**Description**	**Source**
Predator Proof Night Corrals	Protection for livestock from snow leopards overnight	Jackson and Wangchuk., 2010
Livestock Insurance	Financial compensation for livestock killed	Mishra et al., 2003
Alternative Incomes	Non timber forest products (e.g. mushrooms), ecotourism	Maheshwari and Sathyakumar, 2019
Education and Awareness	Local involvement in conservation initiatives	Hanson et al., 2019
Geospatial Hotspots	Identify depredation hot spots across landscape	(Mccarthy & Chapron, 2003)

Habitat Suitability Mapping	Identify areas of high snow leopard suitability	Bagchi, 2019
Alternative Husbandry Practices	Change husbandry practices to avoid depredation	Jackson et al., 1996
Rangeland Management	Maintain rangeland food source for both livestock and native ungulates	Shrestha, Kindlmann, Jnawali, 2012
Native Ungulate only pastures	Reduce competition between livestock and wild ungulates	Mishra et al., 2003

These efforts can act as a starting point for the discussion of conflict resolution in SPNP. Some of these strategies are already in their early implementation stage in SPNP. The current state of these strategies will be discussed in the section that follows, supported with qualitative notes collected during surveys that highlight the strengths and weaknesses of each approach. The second half of this chapter will then explore of future of conflict resolution in SPNP. It offers potential management implications based off of findings from chapters 3 and 4 of this thesis, once again supported by qualitative notes, that could improve the current state of conflict resolution in SPNP.

5.1 Current State of Conflict Resolution Efforts in SPNP

The year of 2018 marked the beginning of a partnership between DNPWC park management and WWF Nepal in the name of snow leopard conservation in SPNP. In the time since, this partnership has implemented a number of initiatives centered around snow leopard-human coexistence such as a 2018 baseline assessment of livestock depredation, the creation of four predator proof night corrals, and the development of a livestock insurance scheme in Bhjer (Shrestha and Gurung, 2022). This work has occurred alongside a separate government funded Wildlife Damage Relief Fund that offers relief up to 30,000 to community members who lose their livestock from a protected predator such as the snow leopard (Shrestha and Gurung, 2022). As for the local communities themselves, they also currently apply conflict resolution strategies such as spiritual practices, increased livestock guarding, and ecotourism livelihood development. The current state of each of these efforts will be discussed in turn supported from evidence in chapters 3 and 4, as well as qualitative notes captured during surveys to offer local perspectives on the effectiveness of each effort.

5.1.1 Livestock Relief Programs

The Wildlife Damage Relief Fund is a government relief program in place that offers financial support when livelihood is damaged by protected wildlife in Nepal. In SPNP this fund can offer up to 30,000 rupees per livestock lost to carnivore depredation, and in the year 2022 the communities of Dolpo received a reported 10 million rupees distributed across 387 households (Shrestha and Gurung, 2022). With a total household population of 772 in SPNP (Khanal et al., 2020), this report suggests that 50% of the households in SPNP are benefiting from this relief program. Our questionnaire provided similar results, as it asked how many respondents received any form of relief following a depredation event. Of those respondents who indicated in the questionnaire that their livestock had been killed by a snow leopard (n = 97), just under half (45%) indicated that they did receive some form of relief, while just over half (55%)

indicated they had not. It is worth noting that the data from this research only included individuals that had experienced livestock depredation by snow leopards, whereas the 50% previously mentioned is for all household regardless of livestock ownership and depredation.

Those who indicated that they had successfully received relief from this program were then asked how many rupees they had received. Of those that could remember the average relief, when accounted for number of livestock loss reported in their application, came out to a self-reported 10,100 rupees of relief per livestock. This number is very similar to the reported DNPWC average of 8,500 rupees of relief given per livestock (Shrestha and Gurung, 2022). These similarities adds to the credibility of local knowledge and accuracy of data collection. In fact, it may be easy to assume that a respondent would underreport relief given to our questionnaire with hopes of receiving additional compensation, but the average from our questionnaire is greater than that of the reported. If nothing else, this cause be used as justification to the accuracy of local knowledge and data gathered through these types of surveys.

Qualitative notes gathered during surveys provide local insights to perceptions of such relief programs. Overall, many respondents felt that the relief they had received did not compare to the value of their livestock lost. For example, one respondent mentioned that they could sell a goat for 35,000 rupees while the relief scheme would only provide 5,000 rupees. Another indicated that they had received 8,000 rupees for a horse that could sell for 50,000 rupees. A final respondent indicated that after six of their yaks were killed, they received only 30,000 rupees while stating that each yak was worth upwards of 90,000. It was commonplace for the qualitative fieldnotes to detail that respondents were unsatisfied with the amount of relief they are currently receiving, and how it does not measure up to the market value of their livestock. The disparity between perceived market value and reported relief amount is an area that should be addressed in future efforts.

There were also many respondents who experience livestock depredation by snow leopards who did not receive any relief funds. An open-ended question was included in our survey that asked why the respondent believed that they did not receive any compensation despite their eligibility for relief. While open ended questions could in theory generate an infinite number of differing responses, clear common barriers emerged to this relief fund that were repeated amongst respondents. The primary barriers identified by communities as to why they did not receive relief were in order of popularity:1) lack of photo evidence of livestock depredation by snow leopards, 2) applied for relief but never received compensation, 3) lack of knowledge about the relief programs 4) politics surrounding the Snow Leopard Conservation Committee 5) the process is too complex to understand, and 6) the travel time to submit their claim exceeded the compensation they would receive. The current state that gives rise to each barrier will now be examined in turn supported by these qualitative notes.

To begin, lack of photo proof was the most common response as to why an individual felt they did not receive any relief. While this is the general theme of this barrier, respondents often elaborated further on this point. For example, many indicated that they simply did not own a cellphone. Without a cellphone to take a picture of their livestock there is no way to apply for relief. If a respondent did own a phone, many of these phones did not have the ability to take pictures. Further still, if a respondent did have a phone with the ability to take pictures, they did not have access to adequate charging facilities. I experienced firsthand how most villages that I travelled to in SPNP did not have access to electricity. Our field team relied on solar batteries for field equipment. Limited access to modern technology and infrastructure is a clear underpinning of the barrier of requiring photos as proof to access relief funds.

Next, lack of knowledge on the relief program and the complexity of the relief process were two similar reasons highlighted as to why an individual felt they did not relieve relief. The qualitative fieldnotes can provide greater insight into these two challenges, as they highlight that there was misinformation around what the actual process was to successfully apply and receive relief. For example, one respondent suggested that to receive relief you would need to take your photo to a vet who would then verify if the livestock was killed by a snow leopard, and that would cost 5000 rupees. Afterwards, you would need to get letters from the SLCC and park wardens before finally submitting your approval. Another respondent said that you need a printed photo and must pay for the cost of printing, then need to walk down to the park office to submit which is far from many areas in SPNP. This ties into the commonly cited barrier of distance required to report. For many, the trek to the park entrance in Suligard is not worth the relief amount. To return to the point on application complexity, some individuals indicated you could give paperwork to SLCC while others said you needed government approval. This lack of a cohesive understanding on the application process for relief is a clear challenge that currently exists in SPNP and should be addressed to make this program more accessible to the community.

The final barrier respondents identified as the why they had not received relief was that their application had been submitted but they never heard back. This barrier would be challenging to prove but should not be discredited due to the frequency of this complaint. A transparent application process, clear timeline, and independent evaluation of the distribution of relief funds could address these concerns.

A livestock insurance scheme is a separate relief program that has run in parallel to the Wildlife Damage Fund, one that WWF Nepal and DNPWC are looking to integrate. This insurance scheme has been mismanaged in the past, with the largest challenge being the reliance on external funding sources (Shrestha and Gurung, 2022). WWF Nepal is hoping to address this challenge through a combination of insurance premiums paid by the local community and a strategic linkage with the Wildlife Damage Fund (Shrestha and Gurung, 2022) This new livestock insurance scheme is in various stages of application in the park at the time of our fieldwork, with the region of Bhjer the farthest along having already collected premiums and distributed funds. The insurance scheme has not begun in the regions of this study (Phoksundo, Dho Tarap, and Saldang). To learn the current state of approval for such an insurance scheme, our survey asked respondents if they would be willing to pay into an insurance program to protect their livestock and provide relief when their livestock are killed. Most responded favorably (72%), indicating that a relief program could be successful in these areas.

5.1.2 Predator Proof Night Corrals

Predator proof night corrals are one strategy that have been implemented in SPNP as a means of conflict mitigation to reduce livestock depredation. Goats and sheep are often kept inside traditionally built corrals at night in SPNP while larger livestock such as yak and dzo are left to roam. Four predator proof night corrals have been constructed in SPNP, including one in each of our study blocks of Phoksundo, Dho Tarap, and Saldang (WWF Nepal, 2022). WWF Nepal Annual Report revealed that no mass killing events occurred within the predator proof night corrals since their construction despite frequent snow leopard sightings in the vicinity of the corrals (WWF Nepal, 2022). This indicates that the current state of these improved corrals may eliminate mass killing events.

To gain a local perspective on how these four predator proof corrals are perceived in the community our questionnaire asked whether the respondent was aware and/or benefited from them. Results show that most people were aware of predator proof night corrals (74%), but very few benefited from their use (8%). This low number is expected due to the number of predator proof corrals currently built. When discussing predator proof night corrals many points arose that were captured in the qualitative field notes that were not directly captured in the quantitative questionnaire. For example, despite many people not personally benefiting from this conflict resolution strategy, many respondents indicated that they believe predator proof night corrals are the best solution to livestock depredation. Respondents indicated the desire to take initiative and build their own predator proof night corrals if given the resources or knowledge to do so. One respondent even indicated that they would be willing to share the cost of construction with other community members to get one built in their village.

Areas for improvement were also captured in these qualitative notes on how to improve the current predator proof night corrals in SPNP. For example, some respondents indicated that the lack of a solid roof of the current predator proof corrals leads to rain entering the corral. This turns the ground into thick mud rising to the knees of livestock making them sick. Additional concerns surrounded the chosen placement of corrals. Some respondents felt that the corral placement in Shey was in the wrong spot. They indicated that the corral is not currently in use because too many people already reside in that area so there is a lower risk of snow leopard depredation. Instead, they suggested that one should be built in the herding sites where most of the goats and sheep are kept.

Traditional knowledge was also a key topic of discussion that was captured in the qualitative field notes surrounding corral construction. As local communities and snow leopards have a long history of occupying this region, it is no surprise that traditional knowledge has been applied to corrals in the past and present to deter snow leopard predation. Traditional corrals have both positive and negative features that make them more or less susceptible to snow leopard depredation. For example, many traditional corrals are attached to the side of houses. While human presence could be thought to deter snow leopard depredation, mass killing of livestock has been reported in these corrals in villages. Such was the case for one respondent who lost 37 of his goats and sheep in the corral attached to his home. This corral only had a partial door opening that allowed for the snow leopard to get inside. Qualitative notes highlight unique means of deterring snow leopards from traditional corrals such as: burning dung around the perimeter of the corral, building scarecrows, burning juniper.

5.1.3 Additional Conflict Resolution Strategies

The current state of additional conflict resolution strategies was also understood through the quantitative survey and qualitative notes. Some of these additional strategies have also been supported through the DNPWC-WWF Nepal partnership and include formal and non-formal education initiatives, and livelihood support. Other conflict resolution strategies are those carried out by the community independent of external support and include tourism, livestock husbandry strategies, and cultural practices. The current state of each strategy will now be examined in turn.

In the survey we asked about the awareness and support received from two externally funded mitigation measures: formal and non-formal education initiatives and livelihood support. The current state of formal and non-formal education initiatives revealed that 65% of respondents were aware of education programs, while 27% of respondents indicated their household benefited from the program. Qualitative notes highlight a desire amongst respondents for greater awareness and access to these sorts of programs. For example, one respondent indicated that despite finishing zero years of school they were very interested in these sorts of programs but did not know how to be selected to take part. This sentiment was emphasized by another respondent who indicated that it is very important for local people to understand how and where to receive these programs because they currently felt they did not have access to such programs. In terms of the current state of livelihood supports, only 13% of respondents indicated that they were aware of these livelihood support programs, and only 9% of respondents indicated that their household had benefited from them. The disconnect between communities and these livelihood support programs, and their potential impact, can be seen in qualitative notes. For example, one respondent indicated that they only grow enough food to support themselves for two months of the year and must purchase food for the remainder. Another indicated that though livelihood support training exists it does not go to the people who need it most, and likely goes to individuals with the best connections to those that deliver the programs. During fieldwork I witnessed how there was a cooking training program occurring in Phoksundo while many of the individuals we surveyed did not know about it happening.

Ecotourism is a development strategy with the ability to directly benefit from the presence of snow leopards in SPNP while contributing to the economic development of communities. Respondents were asked in the attitude section of our survey if snow leopards benefited their household. Results indicated that over half (55%) of the respondents believed snow leopards did not benefit their household. When compared to other regions of Nepal there is a relatively low level of ecotourism in SPNP. During our five weeks of fieldwork our team encountered perhaps five other groups completing similar trekking routes. Qualitative notes were able to capture the current interest to explore this tourism-based livelihood amongst many of the respondents. For example, one respondent indicated that they had once owned 35 livestock which was later reduced to 11 as a result of livestock depredation. They did not understand the point of continuing with the practice of herding and wished to switch to a tourism-based livelihood. Another two respondents discussed how herding is a hard profession, and how they would switch to tourism if they had the knowledge to do so. At the time of fieldwork a few respondents had already successfully made this switch. Two respondents indicated that they had in fact once been herders but had shifted to tourism as their primary income source. However, local perspectives also highlight that the increase in tourism has not already been without its challenges in SPNP. Some felt that the money community members were supposed to receive from the government as a result of tourism fees are never actually given to the community. As a foreigner trekking in upper Dolpo I was required to pay $500 USD for a ten-day permit. It is unclear who this permit fee benefits. Another complaint of the current state of tourism in SPNP is the increase in garbage that is not properly disposed of. Lastly, one respondent explained how the tourism that currently occurs in SPNP is all fueled by outside agencies, so the local community does not benefit from any tourist presence in the area. While our field team employed only research assistants and support staff from Dolpo, it was not clear if the other foreign groups we passed had done the same.

Various forms of livestock husbandry were used by the community to protect their livestock from carnivores. The most common form of livestock husbandry was increased human presence around livestock practiced by 89% of respondents. Qualitative notes provide a deeper understanding to the cost and challenges to this form of livestock husbandry. One respondent indicated that their daughter spends all day with their livestock to protect them from predators such as the snow leopard. Another mentioned how their young daughter had been startled when a snow leopard attacked her herd while she was there, causing her to fall and injure herself. Livestock guarding dogs was another technique that 49% of respondents indicated they had tried to protect their livestock. Livestock guarding dogs were identified in a global analysis as the most widely beneficial strategy to reduce depredation without negatively impacting large carnivore populations (van Eeden, Crowther, et al., 2018). Qualitative notes from this research suggest that there is a divide between the perception of effectiveness of this technique. Some indicated that guard dogs were successful at livestock protection from snow leopards, but not other large carnivores present at lower altitudes in the park such as the common leopard. Others indicated financial barriers to this technique as they could hardly afford to support themselves so how could they also afford to support a dog. Another indicated that their household used a guarding dog for protection, but the snow leopards got use to it are no longer scared, adding that the dog is now only good for herding purposes. A final strategy was to relocate livestock following a depredation event to areas they perceived as lowed risk, which was used by 74% of respondents.

Lastly, cultural practices were used by many respondents to protect their livestock from snow leopard depredation. The religion of respondents in Dolpo that we surveyed were either Buddhism or Bon-Buddhism. Qualitative notes make it clear that there is a widespread cultural respect for snow leopard amongst the communities. For example. one respondent indicated that woman should not throw stones when defending livestock because that would hurt the heart of the snow leopard. Another held the belief that when you die your soul is transported into the body of a snow leopard. Snow leopards were also repeatedly referred to as the god of the mountains. If an individual lost livestock to snow leopard depredation some felt that the gods had been angered. Many discussed the role of Khoi, which is broadly understood as bad luck or bad karma on your family which leads to more livestock depredation by snow leopards.

Cultural practices were also used as a means of livestock protection. The importance of prayer was highlighted as a means to protect livestock such as the mountain gods lhelusutah or lhutsa. The role of monks was also highlighted as important in livestock protection. Many respondents indicated that their livestock had received blessings ‘chemdu’ from the high llama that livestock would wear around their neck. One respondent explained how they brought a monk to the pastureland to perform rituals after his livestock was killed. All of these cultural beliefs highlight the important connection between culture and conservation in SPNP.

5.2 The Current Balance Between Biodiversity Conservation and Economic Development: Local Perspectives on Snow Leopard Conservation

These above examples demonstrate a clear start to conflict resolution in SPNP. However, the current perceived balance between biodiversity conservation and economic development from the perceptive of local communities is a critical underpinning of conflict resolution. Underlying human-human conflict between local communities pushing for economic development and external organizations pushing for biodiversity conservation has been identified as a key component to coexistence identified around the world (Bhatia et al., 2020; Dickman, 2010; Redpath et al., 2015). In the context of SPNP, human-human conflict can arise between local communities advocating for their livelihood against government, NGO’s, or researchers pushing for greater snow leopard populations.

Based on the results from our questionnaire communities perceive a growing presence of snow leopards and livestock depredation in SPNP. Results indicate that 77% of respondents perceived more snow leopards in SPNP at the time of interview than were present 5 years ago. Furthermore, 66% of respondents perceived more livestock depredation by snow leopards now that what occurred five years ago. To understand these perceptions in greater detail the open-ended question was asked as to the why respondents felt these trends were occurring. By far the most popular response suggested that there are more snow leopards now due to more snow leopard conservation, and these higher snow leopard populations are leading to more livestock depredation. Qualitative notes revealed additional insights on this perception further highlighting this human-human conflict occurring in SPNP. A clear link was identified by many between government and WWF Nepal snow leopard conservation programs and loss of livelihood. For example, one respondent indicated they had experienced more livestock depredation due to the snow leopard conservation efforts by SPNP park staff WWF Nepal. Others indicated that despite conservation groups such as WWF Nepal and SPNP park staff coming to talk about the benefits of snow leopard conservation, their households did not experience any such benefits. Older respondents who lived prior to park foundation in 1984 indicated that the perceived increase in depredation is a result of regulations that prevent retaliatory killing of problem snow leopards that could occur prior to park creation. All of these examples highlight a sentiment felt by many respondents: so many people come in the name of snow leopard conservation, but no one comes to support the communities.

These insights highlight that there are those in the community that feel the balance between economic development and biodiversity conservation in SPNP leans to heavily in favor of the snow leopard. One respondent specifically mentioned that there needs to be a more balanced approach to snow leopard conservation in SPNP that includes the needs of the local communities. Current conflict resolution strategies are a positive step towards achieving this balance, but the current state of the local perspective on snow leopard-human conflict emphasizes the need for further action. Management implications on conflict resolution strategies will now be explored based on the results from this thesis research, supported by the results of the quantitative analysis and qualitative notes.

5.3 Future Conflict Resolution Efforts in SPNP

This research had the applied goal of informing future conflict resolution efforts in SPNP. This section will now explore how each of the current conflict resolution efforts could be built upon to better address coexistence based on the research findings in chapters 3 and 4 of this thesis and supported with qualitative data.

5.3.1 Relief Programs

Relief programs are a reactive strategy that have the ability to offer financial support to individuals who experience livestock depredation. The successful implementation of this program would help meet the economic needs of communities. To make this resolution strategy more successful at meeting these economic needs moving forward, the challenges highlighted by communities should be addressed.

The disconnect between knowledge of relief programs and accessibility to these programs should be improved upon. Nearly every respondent was aware of the program while less than half received any relief. Results from chapter 5 of this thesis reveal how the number of external supports a household benefited from is a significant explanatory variable of attitudes towards snow leopards. Relief programs were one of four external supports from this question. This finding justifies the importance of these relief programs to not only economic development but also to improving the attitudes of communities towards snow leopards, thus supporting biodiversity conservation. The qualitative notes support this notion. For example, one individual said that if there was more relief accessible to her when her livestock are killed, she would feel more positive towards snow leopard conservation. These findings demonstrate the ability for relief programs to address the balance between economic development and biodiversity conservation.

To build greater accessibility towards relief programs many barriers must be addressed moving forward. The requirement of photo evidence was the largest of these barriers identified in our results. Until phones with cameras and adequate charging facilities are available throughout SPNP this barrier will remain insurmountable by many individuals. Adaptations moving forward should be explored in regard to this requirement. The simplest solution would be to remove the requirement for photos, however this could lead to a rise false claims with no method of verification. Another solution could be park staff or SLCC members are given a phone/camera and have it as part of their job duties to verify these depredation events as they happen. Alternately, a SLCC member could physically verify the depredation site as an alternative to photo evidence for those without access to phones.

Another major challenge from the perspective of local communities in conflict mitigation through relief programs is the disparity between perceived market value of livestock and reported relief amount. The qualitative findings in this research indicate a sizeable gap between perceived value of livestock and the compensation that was reported in our questionnaire. This even led some individual to not report their depredation as they felt that the costs incurred from reporting, such as distance to travel to report, printing of photos, etc., did not outweigh the relief amount they would receive. Similar displeasures have been documented in other regions of the world where livestock owners do not even opt to participate in relief schemes all together (Marino et al., 2016). The insurance scheme that WWF Nepal is working to implement in the study region could offer a solution to this barrier. Our results indicate that most respondents would contribute annually to an insurance scheme. A higher relief amount could be met through the combination of insurance premiums and the Wildlife Damage Relief Fund. Findings from chapter 5 also identify how the level of support from external groups such as WWF Nepal or SPNP park staff is a significant explanatory variable in attitude towards snow leopards. This suggests that the continued or increased presence of WWF Nepal and park staff to support this insurance program would also benefit the attitude of communities towards snow leopards. The consolidation of these two programs can also address the challenges of application complexity mentioned by many respondents. Lessons can be applied from other regions of the Himalayas who have already implemented insurance programs. In the Spiti Valley herders contribute a premium to an insurance program that would provide up to 100% market value compensation when a livestock is killed by snow leopards (Mishra et al., 2003b).

A similar amount of relief in SPNP would eliminate the feeling of how the current monetary value of livestock are being undervalued.

5.3.2 Predator Proof Night Corrals

Predator proof night corrals are a proactive conflict resolution strategy that could eliminate the mass killing of livestock by snow leopards. The findings of this thesis research show that while only 17% of livestock depredation events in SPNP occurred in traditional night corrals, these events account for 40% of the total livestock lost. This demonstrates that while attacks on livestock in traditional corrals are less frequent, they are substantially more intense than attacks on grazing livestock. This finding justifies that the construction of these improved corrals could have an exponentially large impact on the reduction of total livestock depredation in SPNP. Furthermore, qualitative notes revealed that the average respondent accepted the occasional loss of livestock to snow leopards. This could be explained through the cultural beliefs of respondents to the snow leopard. However, they expressed that mass killing was not acceptable. Two separate respondents who experienced a mass killing at their traditional corrals expressed extreme anger following the event, with one stating they no longer wished to see snow leopards in SPNP. Similar sentiments are observed in survey responses that indicated 75% of respondent felt mass killing is a problem that local authorities need to address.

Looking towards the future role of predator proof night corrals in SPNP, the pilot program led by WWF demonstrated no mass killing events in their four predator proof corrals since construction. This is a great accomplishment and demonstration of the ability of these corrals. This conflict resolution strategy should continue to scale up and make these corrals accessible to more of the community. At the time of data collection only 8% of respondents reported that their household benefited from predator proof night corrals. This baseline can be used with future data to measure change in benefit over time as additional corrals are constructed in the region. Findings from this thesis can also be used as justification for scaling up this program. Findings from chapter 5 indicate that the number of external supports received, which included predator proof night corrals as one of four efforts, is a significant driver of attitude towards snow leopards. This suggests that the more people who benefit from predator proof night corrals, the more positive the collective attitude towards snow leopards will become. In addition, the perceived change in external supports from groups such as the SLCC, WWF, and government were also shown to be a significant explanatory variable of attitude towards snow leopards. If the community works together with WWF, SLCC, and local government and sees their continued support for such programs, that perception holds the power to further benefit local attitude towards snow leopards.

If more corrals are to be constructed in SPNP, the question then turns to selecting the area that would be most beneficial in reducing livestock depredation in communities that need it the most. Research findings from chapter 3 of this thesis can be used as a tool to aid in this selection process. The hot spots of livestock depredation identified in our predation risk model are the areas where free ranging livestock are most susceptible to future livestock depredation. This map can be used in consultation with the local of current corrals and community members to determine priority areas for corral placement. It should be noted that once corral placement occurs the spatial patterns of depredation should be continuously monitored. A study that examined theoretical models for human-wildlife conflict demonstrated that livestock depredation could be better controlled in highly productive habitats rather than lowly productive habitats (Bagchi, 2019). The study used the strategy of predator proof night corrals as an example: if placed in a low suitability habitat for the snow leopard night corrals could be detrimental as they eliminate a vital food source (Bagchi, 2019). This emphasizes how conflict resolution measures are an adaptive and iterative process opposed to a one time instant solution.

Another barrier to future predator proof corral construction is that of funding. SPNP is a remote protected area with high costs in transporting the resources required to build these predator proof corrals. Findings from this thesis research, such as the number of depredation inside corrals versus outside corrals, the predation risk model, and qualitative notes on the local desire of these corrals, can all be used as justification to appeal to funding agencies. Interestingly, as mentioned in the qualitative notes earlier, one respondent indicated that they would be willing to pay into a community pool to fund these corrals. This gives rise to the idea that the funding of these corrals could be a community effort similar to the insurance scheme. Alternatively, a case study in Mongolia created a Snow Leopard Enterprise that offered financial rewards through the purchase of local handicrafts to communities who agreed to certain conservation objectives such as a ban on snow leopard poaching a wild ungulate poaching (Mishra et al., 2003b). Perhaps a similar setup could be established in SPNP where the financial reward could go towards predator proof corral construction.

5.3.3 Additional Conflict Resolution Efforts

Additional conflict resolution measures can be adapted in the future to better meet the needs of both biodiversity conservation and economic development in SPNP. Education and livelihood initiatives, tourism, animal husbandry, and cultural practices should all be explored in the future to better foster coexistence between humans and snow leopards.

Findings from the quantitative survey clearly indicate that there is a need for greater accessibility to education and livelihood external support initiatives in SPNP. With only a 16% and 9% benefit rate amongst respondents, there is a need to broaden the reach of these programs. In particular, future efforts could be guided by the results from the attitude analysis in chapter 5 of this thesis. At the broad level, this thesis research demonstrated that the number of external supports received is one of the most significant explanatory variables of attitude towards snow leopards. Similar to the relief and predator proof corrals, this finding can be used as a justification for future funding of these programs. More specifically, the analysis in chapter 5 revealed that years of education, gender, and region were also significant drivers of attitude towards snow leopards. That knowledge could then be used to develop future livelihood supports and education programs for the greatest impact. For example, future livelihood support programs could target woman, those residing in upper Dolpo, and designed for those with lower levels of education. This would both increase the reach of this program while providing the maximum benefit to increase attitude towards snow leopards. In terms of formal and non-formal education programs, our results revealed that years of education was a significant contributor for attitude towards snow leopards. With three quarters of our respondents with zero years of education, an increase in positive attitude towards snow leopards would be one of the many benefits to the community from the continuation and expansion of formal education. A similar rationale can be used for non-formal education programs. If these programs are designed to be inclusive of women, available to those living in more remote regions such as upper Dolpo, and accessible to those with fewer years of formal education, they could have the most impact on increasing the positive attitude towards snow leopards.

While tourism in SPNP lags behind other better known national parks in Nepal, it has the opportunity to expand in the future. The ability for tourism to develop into an opportunity to meet both conservation and development needs should be prioritized moving forward. Other studies have demonstrated participation in tourism programs such as homestays result in more positive attitude of community members towards snow leopards (Vannelli et al., 2019). To ensure communities get these positive benefits the current challenges of tourism identified by communities will be easier to address in the near future while tourism numbers remain small. The negative impact of garbage is no stranger to National Parks in Nepal. For example, the problem of garbage and waste removal on Everest is no stranger to the spotlight, commonly referred to in news articles as “the highest garbage dump in the world”. Lessons learnt from Sagarmatha could be applied to SPNP such as regulations about garbage removal by tourists (Pallathadka, 2020). Additional strategies could be taken from this region such as how to meet future tourism needs such as the increase in energy and food demands during peak tourist season and avoid poor environmental management (Aubriot et al., 2019). Sagarmatha National

Park could also be used as a learning opportunity for how local communities should financially benefit from tourism. Some form of knowledge exchange program between the communities of Dolpo and the Sherpa communities could offer huge benefits in the early stage of tourism development. The concerns raised about how current tourism operators are from outside of the Dolpo district, and how current tourism fees do not make their wat back to the communities should both be addressed. Ecotourism specifically would benefit from the increase of biodiversity conservation in SPNP benefits from the presence of snow leopard in SPNP to the local communities that many of the respondents do not currently experience. One perhaps unintentional finding from the predation risk model could indicate the areas where snow leopard tourism could be most successful. These high-risk areas could also be areas that future tourists could visit in hopes of spotting the elusive snow leopard.

Lastly, the importance of culture as a means of snow leopard coexistence should be explored more fully. Local communities currently use a variety of cultural practices to protect their livestock from snow leopards. Their beliefs also show a tolerance towards occasional livestock depredation. Future conflict resolution strategies could incorporate local religions leaders in these efforts.

Chapter 6: Conclusion

6.1 Synthesis and conclusions

Human-wildlife conflict is a global challenge that lies at the intersection of balancing biodiversity conservation with economic development. As the territories of large carnivores increasingly overlap with those of humans around the world, research that spans disciplines is required to identify conflict resolution strategies aimed at finding this balance. In the case of the snow leopard, global conservation pressures for this charismatic large carnivore intersects with local communities trying to make a living in these remote and resource scarce environments. This thesis research is able to identify underlying spatial and attitudinal drivers of conflict that can be used to foster coexistence that benefits both conservation and communities.

The primary aim of this research was to investigate the social and ecological dimensions of snow leopard-human coexistence in Shey Phoksundo National Park to identify:

i) the spatial drivers of livestock depredation

ii) the determinants of local attitudes towards snow leopards.

Each primary aim of this research led to the creation of two unique research questions. The spatial drivers of livestock depredation were met through the ecological dimensions chapter that was able to identify spatial drivers of conflict and the areas with the highest relative risk of conflict. The determinants of local attitudes towards were met through the human dimensions chapter that identified both the attitudes and underlying explanatory factors that give rise to these attitudes.

In chapter 3 I adopted a spatial lens to investigate where livestock are being killed by snow leopards in Shey Phoksundo National Park. I conducted surveys to record the locations of past livestock depredation. Through a novel application of predation risk modelling using Maxent, I was able to identify the conflict hotspots in our study extent. In addition, I was able to highlight the important landscape features that contribute most to the location of this depredation: distance to grassland, distance to large rivers, and distance to villages. Additional factors were also identified to contribute to livestock vulnerability to snow leopard depredation such as elevation, distance to cliffs, and distance to rock land cover. The location of these conflict hotspots and the underlying drivers of livestock vulnerability can be used to develop pathways to coexistence. Both the local communities and external groups can use our predation risk map as a tool when implementing conflict mitigation measures such as increase human presence around livestock, or the location of new predator-proof night corrals. I look now to ensure that the results from this analysis are disseminated so the knowledge makes its way back to the community.

In chapter 4 I adopted a social lens to investigate the attitudes and drivers of attitudes towards snow leopards in Shey Phoksundo National Park. Overall, attitude was demonstrated to be positive towards snow leopards despite the presence of livestock depredation. However, attitudes of those in Upper Dolpo proved to be more negative towards snow leopards than those in Lower Dolpo. These differences appeared most notably when asked questions specifically about snow leopard protection and the presence of snow leopards in the park. I found the variables that best explain the attitudes of local communities towards snow leopards are gender, years of education, region, number of external supports received, and perception towards the amount of support given by local government and NGO's. This understanding of attitudes and drivers of attitude can guide future mitigation efforts in park. Education and awareness initiatives can target women and be designed to be more accessible to those with fewer years of education. Alternative income strategies such as tourism could allow communities to benefit greater from the presence of snow leopards. The path forward should look to incorporate the attitudes and perceptions of local communities to create a future with true coexistence.

In chapter five I explored the current and future state of conflict resolution efforts in SPNP. External strategies that were implemented at time of data collection through government and external agencies include a livestock relief program, predator proof night corrals, formal and non-formal education initiatives, and livelihood support programs. Additional mitigation efforts currently in use by the community include husbandry practices, tourism, and cultural practices. The state of these current efforts highlight an underlying human-human conflict between snow leopard conservation and local economic development. Future conflict resolution efforts were then explored to outline how coexistence can better meet the needs of both biodiversity conservation and economic development.

6.2 Research Strength and Limitations

A major strength to this research is the research approach that it adopted. Instead of using a single lens of focus to investigate snow leopard-human conflict in SPNP, this research sought to combine both a social and ecological lens. Furthermore, it employed quantitative methods of spatial predation risk modelling and attitude questionnaires while simultaneously gathering qualitative input from community members through open ended questions and notes. This broad but purposeful research approach allowed me to draw on a wealth of research on large carnivore-human conflict to guide this interdisciplinary research with the goal of offering the most help towards coexistence.

The results presented in this thesis offer a snapshot view on the perception of local communities towards snow leopards. A strength in the quantitative approach to this attitude research is in its ability to offer a benchmark for future attitudinal research. A quantitative understanding of attitude can easily be compared five, ten, or twenty years into the future if a similar questionnaire is implemented. This change in attitude is critical to understanding how successful coexistence measures are at truly fostering coexistence. On the flip side, the quantitative nature of this research is limited in its ability to gain depth of understanding that qualitative research is known to produce. While this research looked to incorporate this depth through open ended questions and the collection of qualitative notes, it could have been designed entirely focused on qualitative interviews. This study is also limited through the investigation of a single problem carnivore: the snow leopard. As a result, its implications for management were focused only on this relationship between communities and the snow leopard. It is important to acknowledge that the snow leopard is not the only large carnivore that kills livestock in SPNP. Wolves are also present in the region, and attitudes towards wolves have been reported as more negative than those of snow leopards in this region and neighboring regions of the country (Kusi et al., 2020). As a result of this research limitation, the management implications of the attitude research are limited to the context of snow leopards. With that said, many of the strategies such as alternative income or predator proof night corrals could have a similar impact on offering coexistence with wolves.

The spatial analysis of livestock depredation offers many research strengths. Firstly, this is a novel application of predation risk modelling to the context of snow leopards. The research findings from this analysis offers a first look at the spatial drivers of livestock vulnerability to snow leopards on the landscape. Secondly, this research has the strength of applying local spatial knowledge to generate meaningful management results. This research is one of few predation risk model studies that relies solely on local spatial knowledge to identify the location of livestock depredation events. The good predictive performance of this model highlights the validity of local spatial knowledge, and opens the door for future studies to use this technique when government data on livestock depredation does not exist. This could be particularly important for remote communities in developing countries, who are often at the forefront of these conflicts. However, this spatial research does not come without limitations. I want to acknowledge first that our research was based on self-reported instances of livestock depredation during our surveys. While I explained to each respondent that data would be kept confidential to lower the chance of reporting bias, there is the potential for exaggeration of livestock depredation events (Aryal, Brunton, Ji, Barraclough, et al., 2014). This research is also limited in its ability to predict livestock depredation to a relatively small area. Due to the remoteness of the region, available time, and researching funding, I could not reasonably travel to the entire extent of Shey Phoksundo National Park. As a result, the application of our risk model does not apply to the entirety of SPNP, but rather our reduced study extent. Lastly, this study was limited to presence only data. It is widely understood that presence-absence data is better when developing spatial models in the field of ecology. Due to the nature of gathering local spatial knowledge of depredation events it was not possible to collect absence data. This limitation was addressed through applying the best practices in Maxent modeling.

6.3 Recommendations for Policy and Practice

The findings from this research can be used to make recommendations for policy and practice in the case of Shey Phoksundo National Park. Policy that governs SPNP should increasingly look to how it can benefit both biodiversity conservation and economic development if it hopes to achieve coexistence between communities and the snow leopard. In practice, mitigation measures should be designed to in the future to meet the current conflict challenges in SPNP and the past shortcomings of conflict resolution efforts as identified by the communities.

This research highlights the importance of the external supports in promoting more positive attitudes towards snow leopards. These external supports could be most effective if their reach includes women, those with fewer years of formal education, and those residing in upper Dolpo. One of these external supports is livestock relief programs. Both the quantitative and qualitative findings from the questionnaire indicate that the current policy overseeing the relief program is not meeting the needs of the local communities. These should be redesigned to address the barriers of requiring photo evidence, low relief amount, and general lack of knowledge surrounding the programs. Our quantitative survey indicated that three quarters of respondents would be willing to participate in a livestock insurance program where they paid a small premium annually to get access to monetary relief following a livestock depredation event. I can therefor recommend the continued implementation of this insurance program across our study extent if the above barriers are adequately addressed.

Another of these external supports are predator-proof night corrals. It was clear that the majority of respondents felt predator proof night corrals are the best way to protect their livestock from future depredation, making the recommendation for the continuation of this program an easy one. However, I recognize that this is a costly program in a vast region with limited conservation resources. To begin to address this challenge I can recommend that relevant stakeholders use the hotspot map generated from the spatial predation risk model as a tool to help identify the placement of future corrals. This placement should not be done without community consultation, as the qualitative notes presented in this thesis demonstrated that some community members are unhappy with the placement of at least one current predator proof corral.

Additional supports include formal and non-formal education programs and livelihood support initiatives. Based on the fundings of the questionnaire, I recommend that the awareness and accessibility of these programs are increased. Very few respondents had benefited from either of these programs. The ability for such eternal supports to foster better attitude towards snow leopard while simultaneously offer economic development opportunities for local communities speaks to the larger context of this research. Successful human-wildlife coexistence is one that is able to balance both biodiversity conservation and economic development.

6.4 Recommendations for Future Research

There are many ways in which future research can build upon our research and examine snow leopard-human conflict in Shey Phoksundo National Park. This includes additional research for both the social and natural science fields.

Additional research should look to investigate attitudes towards snow leopards in other regions. Only a handful of studies have applied this attitude lens to snow leopard human conflict, and most in recent years suggesting a growing recognition of the importance of this research (Hanson et al., 2019; Kusi et al., 2020; Suryawanshi et al., 2014). Future research could help contribute to this growing understand of attitudes towards snow leopards in Nepal. In addition, future research could take a temporal approach and investigate the change in attitude before and after a conflict mitigation measure is implement. This would provide results that could indicate how well a mitigation measure actually works to foster coexistence, data which is scarce in this field of research.

Future research could also look to investigate the spatial dynamics of snow leopard human conflict. Spatial scale is an important consideration for any environmental spatial modelling. Many recent papers on PRM have emphasized the importance of exploring a variety of spatial scales to determine which provides the most accurate predictions (Goljani Amirkhiz et al., 2018; Miller et al., 2015; Rostro-García et al., 2016). Spatial scale is important as each depredation event will take the values for each covariate at the chosen scale (pixel size), and certain environmental covariates are more pronounced at a given spatial scale. For example, only a fine spatial scale of 20 meters had any predictive power of livestock depredation by tigers in India (Miller et al., 2015). In addition, a multi-scale analysis conducted for tigers and leopards in Bhutan revealed that settlement density was the most influential factor at fine scales, while land-cover was the most influential at broad scales (Rostro-García et al., 2016). These studies highlight the need to conduct predation risk modelling at a variety of spatial scales to assess both the predictive power of the model and the underlying drivers of livestock vulnerability.

Future research that looks to adopt predation risk modelling to the context of livestock depredation by snow leopards could occur in other regions of Nepal or neighboring countries. Not only would hotspot maps be beneficial to guide mitigation efforts, but drivers of livestock vulnerability have demonstrated to be context specific even for the same species of large carnivore. Because this is the first application of PRM to snow leopards, a wide array of locations are open to continue to apply this modelling technique and compare to the results from this study. I suggest that if a study is looking to apply this technique to other regions and will be gathering their own livestock kill site data, to consider incorporating the collection of absence points into their methodology. Our research was limited due to the fact I only have presence data which drove our selection of Maxent to develop our model. Many studies have incorporated absence data collection and applied modelling technique such as general linear models to develop these risk maps (Miller, 2015).

In the end, there is no single strategy that will eliminate conflict between snow leopards and local communities. This thesis sought to produce research that offers a more complete look at the social and ecological dimensions of this conflict. I believe that it is this breadth of understanding needed to create the best pathways to coexistence that will work for both the communities, and the snow leopard.

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Appendix A: Questionnaire Protocol

Administrative Information

Interviewer: ______________________ Date: ______________________

Village:__________________________ Interview Site: ______________

CODE: __________________________ Oral Consent: ______ Initials: __

1. Livestock Holdings

1.1 How many livestock do you own in total? _________________

1.2 How many of each type of the following livestock do you own?

Livestock	# of adults in herd	# of calves in herd
1.2.1 Goats / Sheep		
1.2.2 Cattle (cow, ox)		
1.2.3 Yak / Nak		
1.2.4 Hybrid (Tolbo, Tolmo, Dzo, Dzomu)		
1.2.4 Horses/Donkeys		
1.2.5 Other:		

1.3 Do you have more or fewer livestock than you did 5 years ago?

☐ Fewer ☐ Same ☐ More

2. Snow Leopards & Livestock Depredation

2.1 Have you seen any snow leopards over the past 5 years in areas you graze your livestock?

☐ Yes ☐ No

2.2 Have you seen any signs of snow leopard over the past 5 years in areas you graze your livestock?

☐ Yes ☐ No

2.3 Do you see more or fewer snow leopards (or snow leopard signs) now than 5 years ago?

☐ Less now ☐ Same ☐ More now ☐ Don't know

2.4 Have any of your livestock been killed by snow leopards in the past 5 years? (If yes, proceed to 2.4.1. If no, skip to section 3)

☐ Yes ☐ No

2.4.1 Please provide more information on each instance of livestock depredation:

Year	**Season**	**# of livestock killed**	**Type of livestock killed**	**Location**	**In night corral? (yes/no)**	**QGIS Point?**
						☐
						☐
						☐
						☐
						☐
						☐
						☐

2.5 Have you noticed high risk areas where most of the snow leopard attacks on livestock occur?

☐ Yes ☐ No ☐ Unsure

2.5.1 Where are these high-risk areas? (Record in QGIS)

2.5.2 Which factors do you think determine the location of these high-risk areas? (Check off which factors are mentioned)

	Environment	**Wildlife**	**Human**	**Management**
Factor Rank	___ Slope ___Elevation ___Aspect ___Ruggedness	___Snow Leopard Density ___Naur Density	___Distance to roads/trails ___Distance to villages	___Land use zoning ___Prevention strategies

	___Temperature ___Distance to water ___ Other (Specify) _______________	___Other (Specify) _______________	___Livestock density ___Other (Specify) _______________	___Other (Specify) _______________
Group Rank				

2.6 What do you do when you see a snow leopard attacking your livestock?

☐ Use physical deterrence (stones, noise, torch) ☐ N/A

☐ Do nothing ☐ Other (specify)

____

2.7 If you do not see the attack, what signs demonstrate to you a livestock has been killed by a snow leopard?

____

2.8 Do you report to park authorities when your livestock is killed by a snow leopard?

☐ Yes ☐ No ☐ Unsure

2.9 Do you report to your Snow Leopard Conservation Committee when your livestock is killed by a snow leopard?

☐ Yes ☐ No ☐ Unsure

2.10 Have you heard of a snow leopard being killed by someone in retaliation to livestock killing?

☐ Yes ☐ No ☐ Don’t know

2.10.1 If yes, can you tell us more about it?

2.11 Has the amount of your livestock killed by snow leopards changed over the past 5 years?

☐ Less now ☐ Same ☐ More now ☐ Unsure

2.11.1 Why do you think this?

---

3. Attitudes Towards Snow Leopards

3.1 How do you feel about the following statements?

Attitude Statement	**Disagree**	**Neutral**	**Agree**	**Don't Know**
3.1.1 The nature and wildlife in Shey Phoksundo is a global treasure	☐	☐	☐	☐
3.1.2 The nature and wildlife in Shey Phoksundo should be conserved	☐	☐	☐	☐
3.1.3 If someone loses their livestock in a mass killing, it is okay for them to kill the snow leopard	☐	☐	☐	☐
3.1.4 Snow leopards provide benefits to my household	☐	☐	☐	☐
3.1.5 My livelihood is more important than snow leopard	☐	☐	☐	☐
3.1.6 In this household, Icannot tolerate snow leopards killing a single livestock	☐	☐	☐	☐
3.1.7 I would be happier if zero snow leopards lived in Shey Phoksundo in the future	☐	☐	☐	☐
3.1.8 Snow leopards killing livestock is an acceptable risk to herding (if it is not mass killing)	☐	☐	☐	☐
3.1.9 Snow leopard mass killing livestock is a problem that local authorities need to address	☐	☐	☐	☐
3.1.10 I would want to implement solutions to livestock killings by snow leopards if I knew how	☐	☐	☐	☐

3.1.11 I would be willing to work with authorities to implement solutions to protect snow leopards	☐	☐	☐	☐
3.1.12 Snow leopards deserve protection	☐	☐	☐	☐

3.2 Which benefits do snow leopards provide to your household? (ask if agree to 3.1.4)

☐ Ecological ☐ Socio-cultural

☐ Economic ☐ Other (specify)

____

4. Livestock Husbandry and Conflict Mitigation Strategies

4.1 Are you aware of any husbandry strategies to protect your livestock from being killed by snow leopards?

☐ Yes ☐ No ☐ Unsure

4.2 Have you tried any husbandry strategies to protect your livestock from being killed by snow leopards without external support? (If yes, proceed to 4.2.1 If no, skip to 4.3)

☐ Yes ☐ No ☐ Unsure

4.2.1 Which husbandry strategy have you tried to protect your livestock without external support? (select all that apply)

☐ Predator-proof night corral ☐ Increased human presence around livestock

☐ Livestock Guarding Dogs ☐ Relocating livestock to lower risk areas

☐ Other (specify) ____

4.3 What is the biggest factor limiting you from using additional husbandry strategies to protect your livestock without external support?

☐ Cost ☐ Time ☐ Awareness & Education ☐ Other (specify)______________

4.4 Are you aware of external supports to prevent or mitigate conflict with snow leopards? (If yes, proceed to 4.4.1, if no skip to 4.6)

☐ Yes ☐ No ☐ Unsure

4.4.1 If yes, which supports are you aware of?

Support	**Aware of support?**
Relief	☐ Yes ☐ No
Livelihood support	☐ Yes ☐ No
Non-formal/formal education	☐ Yes ☐ No
Improved corrals	☐ Yes ☐ No

4.5 Has your household benefited in the past 5 years from any external support to prevent or mitigate conflict with snow leopards? (If yes, proceed to 4.5.1. If no, skip to 4.6)

☐ Yes ☐ No ☐ Unsure

4.5.1 Which external support have you benefited from?

Support	**Benefited from?**
Relief	☐ Yes ☐ No
Livelihood support	☐ Yes ☐ No
Non-formal/formal education	☐ Yes ☐ No
Improved corrals	☐ Yes ☐ No

4.6 In the past 5 years, did you receive any relief through any insurance scheme when your livestock was killed by a snow leopard? (If no proceed to 4.6.2,if yes skip to 4.7)

☐ Yes ☐ No ☐ Unsure

4.6.2 Why did you not receive any relief?

____

4.7 Would you be willing to contribute some amount annually to an insurance scheme if that meant you would get relief for your livestock if killed by snow leopard?

☐ Yes ☐ No ☐ Unsure

4.8 Over the past 5 years, have you seen a change in the amount of external support prevent or mitigate conflict with snow leopards?

☐ Less now ☐ Same ☐ More now ☐ Unsure

5. Attitudes Towards Snow Leopard Conservation

5.1 How do you feel about the following snow leopard conservation strategies?

Conservation Measure	Negative	Neutral	Positive	Don't Know
5.1.1 Livestock Insurance Schemes	☐	☐	☐	☐
5.1.2 Predator-Proof Night Corrals	☐	☐	☐	☐
5.1.3 Livestock Guarding Dogs	☐	☐	☐	☐
5.1.4 Relocating my livestock to lower predation risk areas	☐	☐	☐	☐
5.1.5 Ban on killing snow leopards	☐	☐	☐	☐
5.1.6 Ban on killing snow leopard prey	☐	☐	☐	☐
5.1.7 Adopting alternative income strategies (e.g. tourism)	☐	☐	☐	☐
5.1.8 Education and Awareness initiatives	☐	☐	☐	☐
5.1.9 Native ungulate only pastures	☐	☐	☐	☐
5.1.10 Alternative husbandry practices (increased human presence)	☐	☐	☐	☐

5.2 Over the past 5 years, how do you feel about the amount of support provided by the following groups involved in snow leopard conservation?

Conservation Measure	Less	Neutral	More	Don't Know
5.2.1 Park Management	☐	☐	☐	☐
5.2.2 Community leaders and groups engaged in conservation (e.g. SLCC, BZUC)	☐	☐	☐	☐

5.2.3 Non-Governmental Organizations	☐	☐	☐	☐

6. Socio-Demographic Information

Lastly, Ihave a few questions that will help us understand some additional factors that could influence attitudes towards snow leopards. These factors have been identified as important from other research studies looking at large carnivore-human conflict in the past.

6.1 What is your age? _________________

6.2 What is your sex? ______________

6.3 What is your ethnicity? ______________

6.4 What is your religion? _______________

6.5 How many years of education have your completed? ________________

6.6 What is your caste? _________________

6.7 What percentage of your household income comes from the following sources:

☐ Herding (%) _________________ ☐Tourism (%) ______________________

☐Agriculture (%) ________________ ☐Other (specify & %) _________________

☐ Yartsa (%) _________________

6.8 Do you know if your parents, grandparents, and earlier generations were also livestock herders?

☐ Yes ☐ No ☐ Unsure

7. Additional Information

7.1 Are there any additional comments you would like to make at this time?

Appendix B: Correlations Matrix of Spatial Variables

Table C.1: Correlation matrix of 11 predictor variables that were hypothesized to influence relative risk of livestock depredation by snow leopards.

	grassland	**rock**	**Prime SL habitat**	**village**	**elevation**	**gullies**	**Large river**	**roughness**	**slope**	**cliff**
Grassland	1.00	0.09	0.43	0.23	0.57	0.35	0.28	0.04	0.01	-0.10
Rock	0.09	1.00	0.12	-0.26	-0.24	0.24	0.09	-0.01	0.19	-0.22
Prime SL habitat	0.43	0.12	1.00	0.04	0.46	0.44	0.33	0.05	-0.13	0.11
Village	0.23	-0.26	0.04	1.00	0.36	0.00	-0.04	0.00	-0.01	-0.09
Elevation	0.57	-0.24	0.46	0.36	1.00	0.41	0.45	0.13	-0.01	0.06
Gullies	0.35	0.24	0.44	0.00	0.41	1.00	0.36	0.05	0.15	-0.18
Large river	0.28	0.09	0.33	-0.04	0.45	0.36	1.00	0.14	0.11	-0.07
Roughness	0.04	-0.01	0.05	0.00	0.13	0.05	0.14	1.00	0.06	0.03
Slope	0.01	0.19	-0.13	-0.01	-0.01	0.15	0.11	0.06	1.00	-0.34
Cliff	-0.10	-0.22	0.11	-0.09	0.06	-0.18	-0.07	0.03	-0.34	1.00

Appendix C: Getis-Ord Gi Values

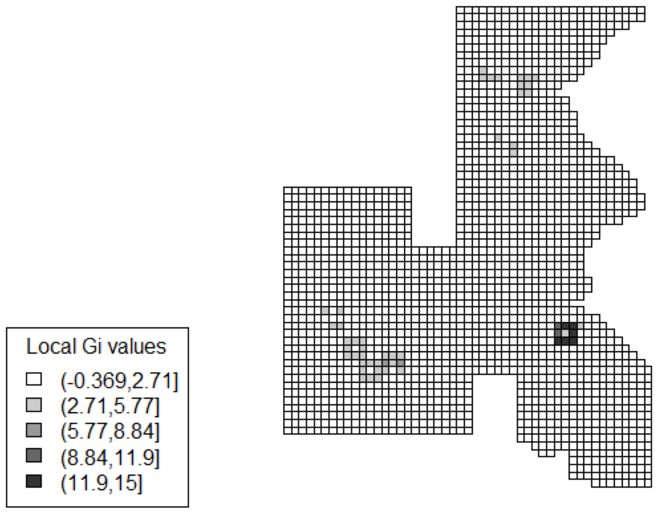

Figure D.1: Local Gi values for livestock depredation at a quadrat resolution of 1000m.

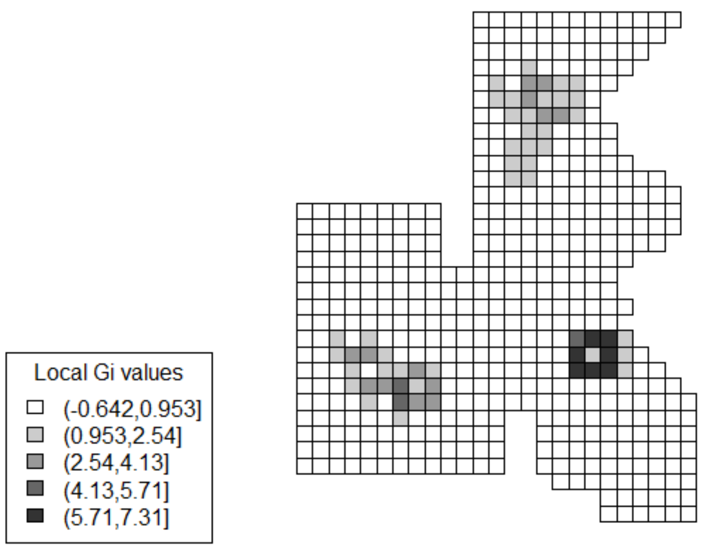

Figure D2: Local Gi values for livestock depredation at a quadrat resolution of 2000m

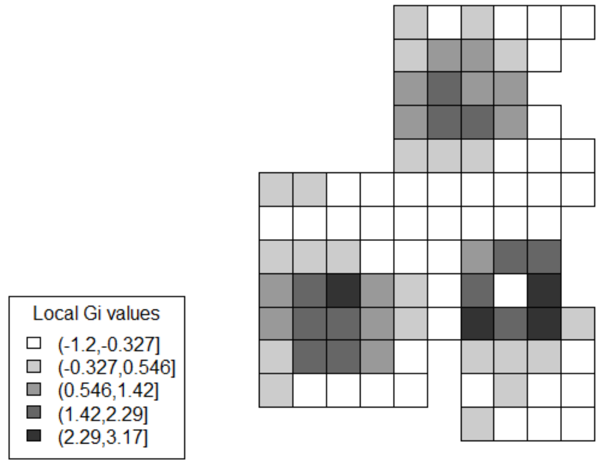

Figure D.3: Local quadrat resolution for livestock depredation at a quadrat resolution of 5000m.