Examining livestock depredation and the determinants of people's attitudes towards snow leopards in the Himalayas of Nepal

Kabindra Shahi, Siddhartha Aryal, Rupak Kumar Blon and Gopal Khanal

Abstract Livestock depredation by snow leopards *Panthera uncia* poses a significant threat to the livelihoods of pastoral communities and engenders negative attitudes towards the species, threatening its survival. We conducted 104 semi-structured interviews within local communities (livestock herders and owners) in the Nyesyang valley of Manang District, in the Annapurna Conservation Area, western Nepal, to assess the status of livestock depredation and community attitudes towards snow leopards. During February 2016–January 2018, respondents reportedly lost 279 livestock to snow leopards (mean loss of 1.3 livestock per household), comprising 3.7% of the total stockholding in 2018. This loss amounts to a monetary loss of USD 319 per annum for each household. Only half of the households who lost livestock to snow leopards in the previous 2 years received compensation from the Conservation Area. Almost an equal proportion of respondents held positive (42%) and negative (41%) attitudes towards snow leopards. An ordered logistic regression analysis revealed that being a woman, being illiterate, owning a high number of large-bodied livestock and relying primarily on agropastoralism were factors associated significantly with negative attitudes towards snow leopards. We recommend focusing conservation education on illiterate community members and engaging more women in conservation programmes, along with a community-based insurance scheme for large-sized livestock to mitigate losses and improve local community attitudes towards snow leopards.

Keywords Attitudes, compensation process, human–wildlife conflict, livestock depredation, Manang, Nepal, *Panthera uncia*, snow leopard

Supplementary material for this article is available at doi.org/10.1017/S0030605322000928

Kabindra Shahi (orcid.org/0000-0003-3469-9940) Centre for Ecological Studies, Lalitpur, Nepal

Siddhartha Aryal (Corresponding author, orcid.org/0000-0003-2385-5282, sidaryal20@gmail.com) Institute of Forestry, Hariyokharka, Pokhara, Nepal

Rupak Kumar Blon, Division Forest Office, Makwanpur, Nepal

Gopal Khanal (orcid.org/0000-0001-6628-0015) Department of National Parks and Wildlife Conservation, Government of Nepal, Kathmandu, Nepal

Received 7 November 2021. Revision requested 4 April 2022.
Accepted 18 July 2022. First published online 2 February 2023.

Introduction

The co-existence of large carnivores with people remains challenging because of the common resources shared by humans, livestock, large carnivores and their wild prey (Woodroffe et al., 2005). Snow leopards *Panthera uncia* inhabit the mountainous areas of Central Asia and the Himalayas and play a crucial role in regulating ecosystem health and processes (Ripple et al., 2014). However, the decline in their prey base (McCarthy & Chapron, 2014), habitat loss (Forrest et al., 2012), traditional herding practices involving minimal protection from predators (Tiwari et al., 2020), and livestock-based livelihoods (Kusi et al., 2020) have escalated livestock depredation by snow leopards, causing human–snow leopard conflict (Oli et al., 1994; Namgail et al., 2007; Mishra et al., 2016). Livestock depredation by snow leopards poses a serious threat to the livelihoods of agropastoral communities (Aryal et al., 2014) as local herders suffer substantial economic losses from such depredation (Hussain, 2000; Namgail et al., 2007; Mishra et al., 2016; Kusi et al., 2020; Tiwari et al., 2020), which sometimes leads to shifts in livelihood options (Vannelli et al., 2019). Consequently, livestock depredation can lead to retaliatory killing of snow leopards and often engenders negative attitudes towards the species (Oli et al., 1994). Such conflict is expected to escalate because of stringent conservation laws and decreasing natural prey species for snow leopards (Namgail et al., 2007; Aryal et al., 2014). Various approaches are being employed to mitigate this conflict, including compensation for livestock loss, livestock insurance schemes, predator-proof corrals and guarding of livestock by dogs. However, the success of these approaches depends largely upon the effective involvement of local communities in conservation (Jackson & Wangchuk, 2004), which in turn requires an understanding of local community attitudes towards snow leopards (Bagchi & Mishra, 2006; Dickman, 2010).

Several studies have examined the factors driving agropastoral community attitudes towards snow leopards and their conservation (Bagchi & Mishra, 2006; Li et al., 2014; Suryawanshi et al., 2014; Hanson et al., 2019; Chetri et al., 2020; Kusi et al., 2020). These studies showed that source of livelihood, age, religion, education level (Hanson et al., 2019), livestock holdings and losses (Suryawanshi et al., 2014), and the presence of alternative sources of livelihood (Bagchi & Mishra, 2006) are significant predictors of these attitudes. Adherence to Buddhism (Li et al., 2014), higher

education levels (Hanson et al., 2019) and diversified livelihoods (Bagchi & Mishra, 2006; Vannelli et al., 2019; Chetri et al., 2020) have been found to influence these attitudes positively, whereas livestock-based livelihoods (Suryawanshi et al., 2014), lack of compensation mechanisms, higher livestock losses (Kusi et al., 2020), agropastoral occupation and households with illiterate and older family members (Chetri et al., 2020) have a negative influence on these attitudes. One of the first studies of local community attitudes towards snow leopards, conducted in Manang District in central Nepal, found that the majority (> 60%) of respondents held a strongly negative attitude towards snow leopards and expressed extermination of snow leopards as the only solution for reducing this conflict (Oli et al., 1994). Since then, the sustained implementation of conservation efforts (Chetri et al., 2020) and changes in the socio-economic context (e.g. changes in pastoral practices, increases in mean annual income and tourism activities) have occurred in Manang (Chapagain, 2016). Although livestock depredation by snow leopards in Manang remains a concern, little is known about current levels of livestock depredation and local community attitudes towards snow leopards.

Here we assess the extent of livestock loss and identify the factors influencing local community attitudes towards snow leopards in Manang District. We hypothesized that educated young men belonging to households that are less dependent on agropastoral livelihoods and respondents who had experienced no livestock losses in the last 2 years would hold positive attitudes towards snow leopards. Because of the plethora of conservation efforts initiated by Annapurna Conservation Area since the 1990s, we expected that the majority of local communities would hold positive attitudes towards snow leopards. Our findings will be useful for designing specific target-based conservation interventions, so that the long-term persistence of snow leopards is possible through the building of sustained pro-snow leopard local stewardship.

Study area

The study was undertaken in the Nyesyang valley, which lies in the north-east of Manang District, in the Annapurna Conservation Area, Nepal (Fig. 1). The c. 700 km² valley comprises nine clustered villages and settlements (Fig. 1). The vegetation of the area is characterized by coniferous and conifer–birch mixed forests at lower elevations and grasslands mixed with scrub at higher elevations (Lama et al., 2017). Wolves *Canis lupus*, red foxes *Vulpes vulpes* and Pallas's cats *Otocolobus manul* also occur in the area, and blue sheep *Pseudois nayaur* (the main prey of snow leopards) and Himalayan musk deer *Moschus leucogaster* are the wild ungulates present (Lama et al., 2017).

The local economy depends mainly on animal husbandry and crop farming, with tourism becoming more important (Bhuju et al., 2007; Chetri et al., 2017; Baral et al., 2019). Domestic yaks *Bos grunniens*, jhopas (cattle–yak hybrids, *Bos* spp.), cattle *Bos taurus*, sheep *Ovis aries*, goats *Capra hircus* and horses *Equus ferus caballus* are the major livestock species reared. Herders mainly practice a traditional herding system in which accessible rangelands are used for livestock grazing, with seasonal rotation. Livestock are left to graze at remote and higher-altitude pastures during the summer months (June–August), and in winter (December–February) are brought to lower-altitude pastures near the settlements. All residents practice Buddhism and Gurung is the dominant caste.

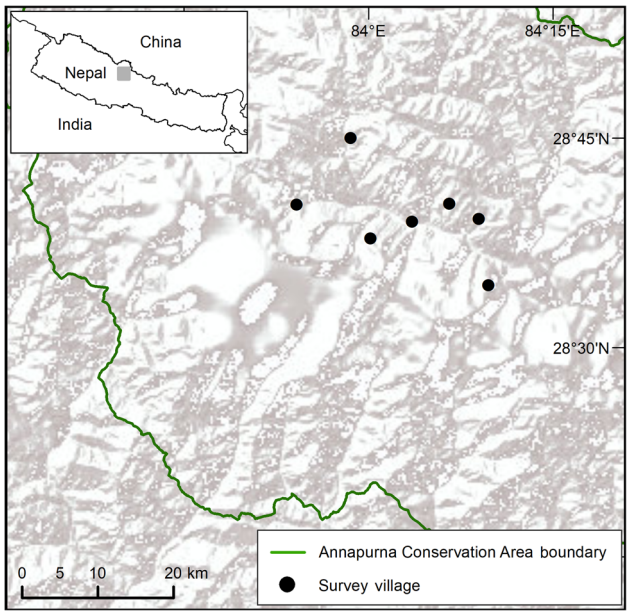

FIG. 1 The study villages in Nyesyang Rural Municipality, Manang, Nepal.

Methods

Data collection

A total of 104 households were selected randomly from the pool of 593 households in seven villages (Khangsar, Bhraka, Tanki Manang, Manang, Ngawal, Ghyaru and Pisang), representing 17.6% of the total households. We conducted face-to-face semi-structured interviews with the head of the household using a pre-tested questionnaire. In the absence of the household head we interviewed another household member > 18 years of age. The questionnaire contained sections pertaining to household demographic and socio-economic characteristics, livestock losses to snow leopards (including the reason for any loss and methods employed to mitigate human–snow leopard conflict), and attitudes of the respondent towards snow leopards (Supplementary Material 1). We asked respondents to report any livestock losses to snow leopards that had occurred

TABLE 1 The questions asked of respondents in the study area of the Nyesyang valley, Manang District, Nepal (Fig. 1) and the responses received, which were used to assess the attitudes of pastoralists towards the snow leopard *Panthera uncia*. Response indicates the per cent of the 104 respondents.

Questions	Possible reply	Score	Response (%)
Would you like to see snow leopards in the rangelands of Nyesyang?	Yes	1	17.4
	Unsure	0	3.8
	No	−1	78.8
Should snow leopards be protected inside or outside Nyesyang?	Both	1	21.2
	Inside	1	29.8
	Do not know	0	0.0
	Outside	−1	45.2
	Nowhere	−1	3.8
If snow leopards were to be conserved in Nyesyang, would you support this?	Yes	1	51.0
	Unsure	0	0.0
	No	−1	49.0
Should children be taught about snow leopards in school?	Yes	1	73.1
	Do not know	0	4.8
	No	−1	22.1
Do you think the conservation of snow leopards is beneficial for the environment of Nyesyang?	Yes	1	82.7
	Do not know	0	5.8
	Yes & no	0	3.8
	No	−1	7.7
Where should snow leopards be protected?	Rangelands	1	27.9
	Everywhere	1	26.0
	Only in national parks	0	11.4
	Do not know	0	3.9
	Zoos	−1	25.0
	Nowhere	−1	5.8
What should be done when snow leopards kill your livestock?	They also need food	2	14.4
	Nothing, I can bear it	1	14.4
	Cannot do anything	0	9.6
	Chase it away	−1	35.6
	Kill it	−2	26.0

over the previous 2 years only (February 2016–January 2018) as respondents may find it difficult to recall older cases of livestock depredation. We cross-checked this information with neighbouring respondents. We conducted the study during February–March 2018. We obtained verbal consent from all respondents before the interview. We tested the survey in five households to ensure questionnaire clarity, appropriate length and relevance to the study sites, following which we made some adjustments to the questionnaire prior to the full survey.

Data analyses

We summarized the household-level livestock loss over 2 years, segregated by species and village. We computed descriptive statistics for respondent socio-demographic characteristics, livestock depredation, monetary loss incurred and livestock holding. We evaluated the attitudes of respondents based on seven structured questions (Table 1) following Suryawanshi et al. (2014). These questions were related to wider aspects concerning snow leopards and their conservation, providing a more holistic and detailed portrayal of community attitudes towards the species. Summing the scores of these questions produces a composite attitude score ranging from −8 to +8. An overall mean attitude score was calculated by adding the scores of the responses to all seven questions of all respondents and dividing by the total number of respondents. Following Suryawanshi et al. (2014), we categorized composite scores of −8 to −2 as negative attitudes, −1 to +1 as neutral and +2 to +8 as positive. The negative, neutral and positive categories (coded as −1, 0 and 1, respectively) were used as the response variable in the regression analysis.

Because there were three categories (i.e. negative, neutral and positive) and an ordered response variable, we performed an ordered logit regression analysis to assess the influence of socio-demographic factors (Table 2) on attitudes towards snow leopards (the response variable). In the ordered logit model, the observed ordinal response variable (y; i.e. attitude) is a function of an unmeasured variable (y'). The continuous latent variable (y') has various threshold points (k_i) and the observed variable (y) depends on

TABLE 2 Predictor variables selected to examine questionnaire respondent attitudes towards snow leopards via ordinal logistic regression.

Variable name	Variable description	Variable type
Age	Respondent age	Continuous
Gen	Respondent gender (0 = woman, 1 = man)	Binary
Edu	Respondent education level (0 = illiterate, 1 = literate)	Binary
LBL	Total number of large-bodied livestock (yaks, horses, jhopas) owned by respondent	Continuous
SBL	Total number of small-bodied livestock (cattle, sheep, goats) owned by respondent	Continuous
Occ	Respondent dominant occupation (0 = agropastoralist, 1 = non-agropastoralist)	Binary
TLL	Total number of livestock lost through predation in the previous 2 years	Continuous

whether the latent variable (y') has crossed a particular threshold or not. For example, in our case, the ordinal category (m) = 3:

$$y = \begin{cases} -1 & \text{if} \quad y_i' < k_1 \\ 0 & \text{if} \quad k_1 < y_i' < k_2 \\ 1 & \text{if} \quad y_i' > k_2 \end{cases}$$

Prior to running the ordered logistic regression analysis, we used a variance inflation factor to check for multicollinearity between the explanatory variables. We did not use highly correlated variables (variance inflation factor > 5) in the same model. Additionally, we ran a test to evaluate the proportional odds assumptions (Agresti, 2019) and the results confirmed proportional odds compliance and suitability of using an ordered logistic regression model. We developed 20 exploratory candidate models. We compared the relative support for these models using the Akaike information criterion corrected for small sample sizes (AICc; Supplementary Table 1; Anderson & Burnham, 2013). The predictor variables, their types and how they are coded in our analysis are presented in Table 2. We performed all of the data analyses using *R 4.0.1* (R Core Team, 2017).

Results

Respondent characteristics

Of the 104 respondents most were men (78.8%). Literate respondents (73.0%) predominated over illiterate (27.0%). The age range of the respondents was 25–83 years, with a mean age of 50. Mean family size was 5.3 individuals (range 3–10). All of the respondents followed Buddhism. The majority of respondents (55.8%) depended on both tourism and the agropastoral system for their livelihood, 36.5% depended completely upon the agropastoral system, and only a few (7.7%) relied solely on tourism as their source of income.

Livestock holdings and losses

Goats, sheep, yaks, jhopas, horses and cattle were the commonly reared livestock. Overall, we recorded a total of 3,666 livestock owned by the respondents, with a mean of 35.3 livestock per household. Goats and yaks were the dominant species, with means of 14.9 and 13.9 per household, respectively. In 2016–2017 and 2017–2018, respectively, 56 and 34 households reported 145 and 134 livestock lost to snow leopards. On average, each household lost 1.4 and 1.3 livestock to snow leopards in 2016–2017 and 2017–2018, respectively, constituting 3.7% of total livestock holdings in 2017–2018. Yaks were the most highly predated livestock (mostly young yaks; 80.7% of livestock predated in 2016–2017 and 58.9% in 2017–2018), followed by goats (6.2% in 2016 and 30.6% in 2017), and horses and cattle were predated in smaller numbers (Table 3). Amongst the seven villages, Ngawal

TABLE 3 Type, number and estimated economic cost of livestock depredation in seven villages in the Nyesyang valley, Manang District, Nepal, during February 2016–January 2018.

Livestock	Number lost in 2016–2017	Number lost in 2017–2018	Mean ± SD economic cost, USD (2016–2017)	Mean ± SD economic cost, USD (2017–2018)	Mean price (USD) per livestock[1]
Goats	9	41	8.65 ± 42.06	39.42 ± 153.54	M = 100, Y = 25
Sheep	0	0			M = 100, Y = 25
Yaks	117	79	311.54 ± 529.60	214.42 ± 725.80	M = 700, Y = 150
Cattle	12	5	14.71 ± 55.83	5.58 ± 39.18	M = 300, Y = 70
Jhopas	0	0			M = 500, Y = 85
Horses	7	9	10.10 ± 47.96	33.17 ± 170.61	M = 850, Y = 150
Combined (all livestock)	145	134	345.00 ± 541.22	292.60 ± 745.83	

[1]M, Mature; Y, Young.

TABLE 4 Model-averaged parameter estimates of the ordered logistic regression models and 95% CIs describing respondent attitudes towards snow leopards in the Nyesyang valley, Manang District, Nepal, during February–March 2018.

Variables[1]	Estimate[2]	Adj. SE	95% CI	z	Pr(>|z|)	Relative importance
Gen	2.435	0.681	1.099 to 3.770	3.573	0.000353***	1.00
Occ	1.736	0.576	0.607 to 2.865	3.013	0.002588**	0.99
Edu	1.563	0.574	0.438 to 2.688	2.722	0.006487**	0.95
LBL	−0.035	0.014	−0.063 to −0.007	2.416	0.015690*	0.91
TLL	−0.187	0.096	−0.375 to 0.001	1.946	0.051639	0.78
SBL	0.007	0.006	−0.001 to 0.020	1.122	0.261866	0.59
Age	−0.003	0.009	−0.045 to 0.018	0.320	0.748758	0.33
−1|0[3]	1.894	0.917	0.096 to 3.691	2.065	0.038940*	
0|1[3]	3.874	0.994	1.925 to 5.823	3.896	9.78×10^{-5}***	

[1]Described in Table 2.
[2]Averaged across the top three models (ΔAIC < 2).
[3]−1|0 represents the threshold between negative and neutral attitudes towards snow leopards and 0|1 represents the threshold between neutral and positive attitudes. Parameter estimates of −1|0 (negative|neutral) and 0|1 (neutral|positive) represent the thresholds such that attitude (y) is negative if $y_i' < 1.894$, netural if $1.894 < y_i' \leq 3.874$ and positive if $y_i' > 3.874$.
*P < 0.05; **P < 0.01; ***P < 0.001.

had the highest livestock loss (11.6% of total livestock holdings) in 2017–2018 and Khangsar had the highest loss (15.1%) in 2016–2017 (Supplementary Table 2). On average, the monetary loss for each household amounted to USD 318.8 per annum (Table 3). Livestock depredation by snow leopards showed a distinct seasonal pattern, with the highest losses during winter (32.7%), followed by spring (24.0%), summer (11.5%) and autumn (6.7%); c. one-quarter of respondents (25.1%) were unsure about the seasonal pattern of livestock depredation. The majority of livestock losses occurred at night (52.9%), followed by morning (11.5%), afternoon (9.6%) and at dusk (1.9%). The remainder of the respondents (24.1%) were unsure about the daily pattern of livestock depredation.

Perceived causes and mitigation measures of depredation

The majority of respondents (87.5%) viewed the leading cause of depredation to be the ease with which snow leopards could kill livestock, followed by unsupervised grazing (5.8%), an increasing number of snow leopards (4.8%) and insufficient natural snow leopard prey (1.9%). Of the 67 households that had lost livestock to snow leopards during the 2 years of study, c. half (49.3%) received compensation from the Annapurna Conservation Area, although this was meagre (< 50 USD per livestock head). Nearly two-thirds (63.5%) of the respondents felt that adequate and rapid payment of compensation should be provided for losses incurred, followed by 18.3% of respondents who believed guarded grazing should be practised. Although 10.5% of respondents were unsure about appropriate mitigation measures, only a few (7.7%) thought exterminating snow leopards from the area was the only option for minimizing livestock depredation. Despite the availability of a livestock insurance scheme to help offset the costs of depredation, only 18.3% of the respondents were actively participating in it.

Attitudes towards snow leopards

The overall mean attitude score towards snow leopards was −0.05 (range = −8 to 8). Similar proportions of residents had positive (42%) and negative (41%) attitudes towards snow leopards, and only 17% of the respondents held neutral attitudes. The responses of the respondents to the seven questions are presented in Table 1. In response to the question on whether they would like snow leopards in the rangelands of Nyesyang (question 1), 17.4% of the respondents replied positively, 3.8% were not sure and 78.8% did not want snow leopards.

From the full sub-model set generated from the global model using the *dredge* function in the *R* package *MuMIn* (Barton, 2022), we selected the top three models based on the criterion of ΔAICc < 2 (Supplementary Table 1). As no single model performed substantially better than other models, we performed model averaging (full averaging) across these top candidate models. The additive influences of the variables gender, occupation, education level, large-bodied and small-bodied livestock owned and total livestock loss received the most support (AICc weights = 0.317). Based on the averaging of the top models, the variables gender, occupation, education level of the respondents and number of large-bodied livestock owned were significant at the 5% level (Table 4). Gender was the most important variable and men held more positive attitudes towards snow leopards than women (Table 4). Respondents dependent primarily on non-agropastoral sources (e.g. owning trekking lodges) held more positive attitudes towards snow leopards than agropastoralists (Table 4). Educated men tended to hold

the most positive attitudes towards snow leopards (Table 4). Owning larger numbers of large-bodied livestock had a negative effect on attitudes towards snow leopards, whereas the number of small-bodied livestock owned did not have a significant influence on attitudes. Similarly, the age of the respondents did not have any discernible influence on attitudes towards snow leopards, nor did the number of livestock lost in the previous 2 years.

Discussion

We estimated the extent of livestock depredation by snow leopards and examined the attitudes of local communities towards snow leopards. The proportion of livestock lost to snow leopards (3.7% of the total livestock holdings) was greater than a previous study in the same valley (2.6%; Oli et al., 1994) and in nearby Mustang District (c. 1.7%; Aryal et al., 2014) but lower than in Nar-Phu region (3.0–4.0%; Wegge et al., 2012) and Shey Phoksundo National Park in the Upper Dolpo region (10.4%; Khanal et al., 2020). The larger livestock holdings compared to the previous study in this region (Oli et al., 1994) could have contributed to the greater livestock losses observed, as livestock holding size and losses are positively correlated (Chetri et al., 2019; Tiwari et al., 2020). Although previous studies reported that goats were the most predated livestock species (Oli et al., 1994; Wegge et al., 2012; Aryal et al., 2014), we found yaks (primarily young yaks) to be the most predated livestock species, followed by goats. This shift in the most predated livestock species is supported by recent studies in the same landscape (Chetri et al., 2019, 2020; Tiwari et al., 2020). The increase in yak numbers, with a higher proportion of young yaks that are left unattended to graze remotely, probably explains this change.

The estimated annual monetary loss per household was USD 318.8, which is higher than that reported by Oli et al. (1994; inflation-adjusted: c. USD 160; Nepal Rastra Bank, 2022) and Aryal et al. (2014; USD 58) but within the range estimated by Tiwari et al. (2020). This higher economic loss can be attributed to the dominant predation of yaks, which are more expensive than goats. We found seasonal variation in the livestock depredation pattern, with higher depredation in winter, as has been noted in earlier studies (Oli et al., 1994; Devkota et al., 2013; Aryal et al., 2014). Free roaming of livestock, unattended herding practices and hibernation of wild prey species, resulting in a reduced availability of wild prey in winter (Aryal et al., 2014), could have contributed to this higher economic loss. Similarly, the majority of the predation incidents occurred during the night. Poorly constructed corrals and greater snow leopard activity during the night could have resulted in greater predation at that time. All of the predation incidents took place in remote pastures, which corroborates the findings of previous studies (Oli et al., 1994; Tiwari et al., 2020; Karki & Panthi, 2021). We noticed that few herders guard their dispersed grazing herds, rendering livestock vulnerable to predation (Bagchi & Mishra, 2006).

We found that an almost equal proportion of respondents held positive and negative attitudes towards snow leopards. The differences in the categorization of attitudes between the previous study in this region (Oli et al., 1994) and ours hindered any quantitative comparison between the two studies. However, it is reasonable to infer that overall people held more positive attitudes towards snow leopards than in the previous study (Oli et al., 1994). This improvement could be in part a result of conservation efforts to increase the awareness of the communities of the benefits of snow leopards, and the establishment of snow leopard conservation committees in the villages. In addition, increased tourism activities could have increased positive attitudes towards snow leopards by providing alternative livelihood opportunities (Vannelli et al., 2019).

People relying primarily on non-agropastoral sources for their livelihoods held more positive attitudes towards snow leopards. This has also been reported in several other studies (Suryawanshi et al., 2014; Hanson et al., 2019; Chetri et al., 2020; Kusi et al., 2020) as these people have more economic opportunities in comparison to agropastoralists. However, people holding a greater number of large-bodied livestock held more negative attitudes towards snow leopards, which corroborates findings from Spiti Valley in the Indian Trans-Himalaya (Suryawanshi et al., 2014). The reason for this could be the higher losses incurred by the owners of such livestock if their animals are predated. However, households with a greater number of small-bodied livestock held marginally positive attitudes towards snow leopards, in contrast to an earlier study (Suryawanshi et al., 2014). A possible explanation is that people can bear the loss of relatively lower-priced livestock if they own a large number.

We found that having lost livestock in the recent past did not significantly influence the attitudes of respondents towards snow leopards (Suryawanshi et al., 2014; Chetri et al., 2020). Consistent with previous research showing that education was strongly associated with positive attitudes towards snow leopards (Suryawanshi et al., 2014; Hacker et al., 2020), we found that literate respondents held positive attitudes. Greater knowledge of existing laws related to wildlife, greater awareness regarding the need for wildlife conservation and increased interaction with conservation agencies could have fostered a positive attitude in literate respondents. We did not find any significant difference in attitudes towards snow leopards with age, although earlier studies reported that older people held more negative attitudes towards snow leopards than younger generations (Røskaft et al., 2007; Suryawanshi et al., 2014). The more positive attitudes of men towards snow leopards compared to women (Røskaft et al., 2007; Suryawanshi et al.,

2014; Chetri et al., 2020) is possibly because of the greater involvement of men in conservation programmes and the fewer economic opportunities for women. The differences in the determinants of attitudes towards snow leopards that we found in comparison to multiple other studies reinforce the argument that such attitudes are multifaceted, complex and site-specific (Røskaft et al., 2007).

A previous study in the same valley reported the killing of snow leopards by herders (Oli et al., 1994), but we did not find any herders who knew of recent retaliatory killings. This was apparently because they were aware of the protected status of the species and the penalties for killing a snow leopard, and held the Buddhist belief that forbids killing of wildlife. The reported absence of retaliatory killing could have resulted in an increased snow leopard population, contributing to the higher livestock depredation rate observed in our study compared to that of Oli et al. (1994). One of the respondents said candidly that 'if there was no law protecting the animal and no penalty for the killing, local communities would certainly kill the animal because it is causing a lot of economic hardship to us'. As stated in the previous study in the valley, lack of willingness to provide information on the killing of snow leopards could be another reason for there being no record of the retaliatory killing of snow leopards (Oli et al., 1994). These matters underscore the importance of specifically targeted conservation strategies that build pro-snow leopard conservation attitudes in local communities, as stringent laws prevent people from conducting retaliatory killings but do not necessarily improve attitudes towards snow leopards.

Constructing sufficient predator-proof corrals in all villages requires substantial human and financial resources, and making the compensation mechanism effective (i.e. a rapid and efficient process providing sufficient payment) will require significant regulatory changes. Targeting conservation education to illiterate people, engaging more women in conservation programmes and extending the community-based insurance scheme supported by the Annapurna Conservation Area to yaks in all villages, if not to all livestock, could mitigate livestock losses and improve attitudes towards snow leopards.

One concern regarding respondents reporting livestock depredation is that they could misattribute depredation by a wolf or red fox as that by a snow leopard. However, research has confirmed that wolves have only returned recently to the Nyesyang valley (Lama et al., 2017), and group discussions revealed that wolves and foxes have not caused significant problems so far. Therefore, it is plausible to conclude that most, if not all, livestock depredation we recorded was attributable to snow leopards. Although we deduced a few reasons for livestock depredation (e.g. large livestock holdings and the absence of retaliatory killing of snow leopards), we acknowledge there could be ecological factors (e.g. declines in snow leopard prey availability) that have contributed significantly to these livestock losses.

Acknowledgements We thank the National Trust for Nature Conservation and Annapurna Conservation Area Project for the research permit and partial funding; the staff of the Unit Conservation Office, Manang, of National Trust for Nature Conservation/ Annapurna Conservation Area Project, especially Babulal Tiruwa and Netra Mahatara, for logistic support; the members of the conservation area management committees and the snow leopard conservation committees for their support; Tashi R. Ghale and his family for their help during the interview surveys; the people of the Nyesyang valley; Keshav Baral and Neeru Thapa for their guidance whilst conducting the study; and two reviewers for their comments.

Author contributions Study design: KS, RKB, GK; interviews: KS, SA; survey response translation: KS, SA; data analysis: KS, SA, RKB; data interpretation; KS, SA, GK; writing: KS, SA, GK.

Conflicts of interest None.

Ethical standards The Institute of Forestry and the Annapurna Conservation Area Project approved the study, and we obtained verbal consent of the interviewees before administering the questionnaire. The research otherwise abided by the *Oryx* guidelines on ethical standards.

References

Agresti, A. (2019) *An Introduction to Categorical Data Analysis*, 3rd edition. John Wiley & Sons, Hoboken, USA.

Anderson, D.R. & Burnham, K.V. (2013) Avoiding pitfalls when using information-theoretic methods. *Journal of Wildlife Management*, 66, 912–918.

Aryal, A., Brunton, D., Ji, W., Barraclough, R.K. & Raubenheimer, D. (2014) Human–carnivore conflict: ecological and economical sustainability of predation on livestock by snow leopard and other carnivores in the Himalaya. *Sustainability Science*, 9, 321–329.

Bagchi, S. & Mishra, C. (2006) Living with large carnivores: predation on livestock by the snow leopard (*Uncia uncia*). *Journal of Zoology*, 268, 217–224.

Baral, R., Subedi, A. & Yadav, S.K. (2019) *Wild Mammals of the Annapurna Conservation Area*. National Trust for Nature Conservation, Annapurna Conservation Area Project, Pokhara, Nepal.

Barton, K. (2022) *MuMIn*: Multi-Model Inference. *R* package version 1.47.1. cran.r-project.org/web/packages/MuMIn/MuMIn.pdf [accessed December 2022].

Bhuju, U.R., Shakya, P.R., Basnet, T.B. & Shrestha, S. (2007) *Nepal Biodiversity Resource Book: Protected Areas, Ramsar Sites, and World Heritage Sites*. International Centre for Integrated Mountain Development, Lalitpur, Nepal.

Chapagain, P.S. (2016) Land and livelihood changes in Upper Manang valley of Nepal Himalayas. *The Third Pole*, 14, 33–41.

Chetri, M., Odden, M., Devineau, O., McCarthy, T. & Wegge, P. (2020) Multiple factors influence local perceptions of snow leopards and Himalayan wolves in the central Himalayas, Nepal. *PeerJ*, 8, e10108.

Chetri, M., Odden, M., Devineau, O. & Wegge, P. (2019) Patterns of livestock depredation by snow leopards and other large carnivores

in the central Himalayas, Nepal. *Global Ecology and Conservation*, 17, e00536.

Chetri, M., Odden, M. & Wegge, P. (2017) Snow leopard and Himalayan wolf: food habits and prey selection in the central Himalayas, Nepal. *PLOS ONE*, 12, e0170549.

Devkota, B.P., Silwal, T. & Kolejka, J. (2013) Prey density and diet of snow leopard (*Uncia uncia*) in Shey Phoksundo National Park, Nepal. *Applied Ecology and Environmental Sciences*, 1, 55–60.

Dickman, A.J. (2010) Complexities of conflict: the importance of considering social factors for effectively resolving human–wildlife conflict. *Animal Conservation*, 13, 458–466.

Forrest, J.L., Wikramanayake, E., Shrestha, R., Areendran, G., Gyeltshen, K., Maheshwari, A. et al. (2012) Conservation and climate change: assessing the vulnerability of snow leopard habitat to treeline shift in the Himalaya. *Biological Conservation*, 150, 129–135.

Hacker, C.E., Dai, Y., Cheng, Y., Zhang, Y., Zhang, Y., Miller, L.J. & Janecka, J.E. (2020) Determinants of herder attitudes towards the vulnerable snow leopard *Panthera uncia* in Yushu Prefecture, China. *Oryx*, 55, 783–790.

Hanson, J.H., Schutgens, M. & Leader-Williams, N. (2019) What factors best explain attitudes to snow leopards in the Nepal Himalayas? *PLOS ONE*, 14, e0223565.

Hussain, S. (2000) Protecting the snow leopard and enhancing farmers' livelihoods. *Mountain Research and Development*, 20, 226–231.

Jackson, R.M. & Wangchuk, R. (2004) A community-based approach to mitigating livestock depredation by snow leopards. *Human Dimensions of Wildlife*, 9, 1–16.

Karki, A. & Panthi, S. (2021) Factors affecting livestock depredation by snow leopards (*Panthera uncia*) in the Himalayan region of Nepal. *PeerJ*, 9, e11575.

Khanal, G., Mishra, C. & Ramesh Suryawanshi, K. (2020) Relative influence of wild prey and livestock abundance on carnivore-caused livestock predation. *Ecology and Evolution*, 10, 11787–11797.

Kusi, N., Sillero-Zubiri, C., Macdonald, D.W., Johnson, P.J. & Werhahn, G. (2020) Perspectives of traditional Himalayan communities on fostering coexistence with Himalayan wolf and snow leopard. *Conservation Science and Practice*, 2, e165.

Lama, R.P., Ghale, T.R., Regmi, G.R., Suwal, M.K. & Lama, T. (2017) Return of the wolf to the Nyesyang Valley, Manang District, Nepal. *Canid Biology and Conservation*, 20, 28–31.

Li, J., Wang, D., Yin, H., Zhaxi, D., Jiagong, Z., Schaller, G.B. et al. (2014) Role of Tibetan Buddhist monasteries in snow leopard conservation. *Conservation Biology*, 28, 87–94.

McCarthy, T.M. & Chapron, G. (2014) *Snow Leopard Survival Strategy: Revised 2014 Version*. Snow Leopard Network, Seattle, USA. snowleopardconservancy.org/wp-content/uploads/2014/10/Snow_Leopard_Survival_Strategy_2014.1-reduced-size.pdf [accessed December 2022].

Mishra, C., Redpath, S.R. & Suryawanshi, K.R. (2016) Livestock predation by snow leopards: conflicts and the search for solutions. In *Snow Leopards* (eds T. McCarthy & D. Mallon), pp. 59–67. Academic Press, Cambridge, USA.

Namgail, T., Fox, J.L. & Bhatnagar, Y.V. (2007) Carnivore-caused livestock mortality in trans-Himalaya. *Environmental Management*, 39, 490–496.

Nepal Rastra Bank (2022) *Nepal Inflation Rate 1964–2022*. tradingeconomics.com/nepal/inflation-cpi?embed/forecast [accessed 21 May 2022].

Oli, M.K., Taylor, I.R. & Rogers, M.E. (1994) Snow leopard *Panthera uncia* predation of livestock: an assessment of local perceptions in the Annapurna conservation area, Nepal. *Biological Conservation*, 68, 63–68.

R Core Team (2017) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Ripple, W.J., Estes, J.A., Beschta, R.L., Wilmers, C.C., Ritchie, E.G., Hebblewhite, M. et al. (2014) Status and ecological effects of the world's largest carnivores. *Science*, 343, 1241484.

Røskaft, E., Händel, B., Bjerke, T. & Kaltenborn, B.P. (2007) Human attitudes towards large carnivores in Norway. *Wildlife Biology*, 13, 172–185.

Suryawanshi, K.R., Bhatia, S., Bhatnagar, Y.V., Redpath, S. & Mishra, C. (2014) Multiscale factors affecting human attitudes toward snow leopards and wolves: attitudes toward snow leopards and wolves. *Conservation Biology*, 28, 1657–1666.

Tiwari, M.P., Devkota, B.P., Jackson, R.M., Bahadur, B. & Chhetri, K. (2020) What factors predispose households in trans-Himalaya (central Nepal) to livestock predation by snow leopards? *Animals*, 10, 2187.

Vannelli, K., Hampton, M.P., Namgail, T. & Black, S.A. (2019) Community participation in ecotourism and its effect on local perceptions of snow leopard (*Panthera uncia*) conservation. *Human Dimensions of Wildlife*, 24, 180–193.

Wegge, P., Shrestha, R. & Flagstad, Ø. (2012) Snow leopard *Panthera uncia* predation on livestock and wild prey in a mountain valley in northern Nepal: implications for conservation management. *Wildlife Biology*, 18, 131–141.

Woodroffe, R., Thirgood, S. & Rabinowitz, A. (eds) (2005) *People and Wildlife: Conflict or Co-existence?* Cambridge University Press, Cambridge, UK.