Journal of Environmental Management 311 (2022) 114763

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Depredation loss drives human–wildlife conflict perception in the Trans-Himalayas

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A R T I C L E I N F O

Keywords:
Human-wildlife conflict
Perception formation
Livestock depredation
Pastoralism
Socio-ecological system
Trans-Himalayas

A B S T R A C T

Communities in and around protected areas are exposed to a higher level of human-wildlife interactions. The conservation practice with persistently adverse local livelihood outcomes can potentially aggravate such interactions leading to conflict. In our study, we examined how perceptions of HWC have formed in a protected area of the Trans-Himalayas whose conservation program collides with a centuries-long tradition of transhumance pastoralism. To examine determinants of depredation and how conflict perception has developed there, along with the socioeconomic and ecological interactions underlying those trends, we collected data using household surveys, key informant interviews, and focus group discussions. We employed Poisson-logit maximum-likelihood hurdle, binary logit, and multinomial ordered logit regressions in order to explore the determinants of annual livestock depredation, predator attacks on the shed, and household-level perceptions of HWC, respectively. Depredation and encounters with wildlife were the principal causes of perceived HWC, and depredation caused an average household-level loss of US $422.5, up to 23.28% of annual income in some households. Predators' attacks on high-quality sheds were relatively infrequent but more common in areas with perceived habitat degradation. Social customs, pastoral practices, and the present compensation mechanism were identified as being antithetical to conflict reduction and sustainable pastureland management. Further analysis revealed that a diversity of livelihoods, however, lowered conflict perception formation. The identified socio-ecological factors will continue to increase depredation, exacerbate perceived HWC, and degrade pastureland unless local conservation authorities take appropriate remedial measures.

1. Introduction

Human–wildlife conflict (HWC), caused by the transformation of natural habitats into anthropogenic landscapes (Pettigrew et al., 2012), is a global problem (Wang, SW & Macdonald, 2006) that has garnered increasing attention in the literature on conservation (Dickman, 2010). In biodiverse regions, livelihoods primarily depend on locally available natural resources that, when procured, intensify human–wildlife interactions and possibly HWC (Woodroffe et al., 2005; Dickman et al., 2011). The literature documents a preponderance of HWC in and around conservation sites—poaching, crop damage, the loss of livestock, human casualties, and the loss of local income sources (Treves and Bruskotter, 2014; Acharya et al., 2016)—where park–people conflict severely undermines the protected areas' integrity and the sustainability of current modes of livelihood (Ikeda, 2004). Because locals are key stakeholders in conservation efforts, it is essential to understand wildlife-induced impacts on their livelihoods and their perceptions of wildlife in order to initiate effective interventions (Travers et al., 2019).

Livestock grazing is traditional practice of animal husbandry used in many societies and a cultural behavior of communities inhabiting the arid and semiarid regions of the world (Weber and Horst, 2011; Mganga et al., 2015). However, by altering predator–prey spatial distribution,

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https://doi.org/10.1016/j.jenvman.2022.114763
Received 22 June 2021; Received in revised form 11 February 2022; Accepted 16 February 2022

behavior and movement and the entire food web, livestock grazing reduces natural prey for predators and, in turn, increases livestock depredation (Miller and Schmitz, 2019). Large carnivores' opportunistic behavior (Ripple et al., 2014; Mkonyi et al., 2017) also results in livestock depredation and can impose significant economic costs at a local level, often in rural areas where households have a relatively low tolerance for economic shocks (Dickman et al., 2011).

HWC is routinely described as a single pair-wise predator–prey interaction. In reality, however, it forms part of complex ecological and economic systems arising from multispecies assemblages (Graham et al., 2005) and often depends on the intensity of loss (Lischka et al., 2018). Conservation's poor cost–benefit ratio at the local level is recognized as a leading factor in the loss of wildlife and the quality of the associated ecosystem. Both non-monetary and monetary mechanisms, the latter including compensation and insurance, revenue sharing, and conservation payments, have been adopted to facilitate the conservation of carnivores and local economic well-being (Dickman et al., 2011). However, impractical compensation mechanisms—the difficult verification of depredation, lengthy application procedures, paltry compensation standards, and inefficient operational resource allocation—have plagued many conservation programs (Chen et al., 2016).

To be functional, mitigation strategies should incorporate locality-specific cultural values and environmental conditions and ensure evidence-based policy in ways such that returns on financial investments can be evaluated (VanEeden et al., 2018). Quantifying HWC's cost and the formation of conflict perception can provide crucial information for designing effective management actions and allow the ethical, sustainable conservation of ecosystems (Yang et al., 2020). Furthermore, understanding psychological drivers of risk and risk-reducing behaviors can help to clarify the formation of perceived HWC (Lischka et al., 2020).

The Trans-Himalayas have hosted transhumance pastoralism for centuries and have thus served as a site for various modern conservation models. The setting indeed offers opportunities to study how regular interactions with wild fauna shape HWC perception, especially with the conservation area (CA) model, which allows studying households that perpetually face the costs and benefits of conservation by virtue of residing inside protected areas. The site examined in our study, Nepal's Upper Mustang region, lies in the Annapurna conservation area (ACA), where people's livelihoods depend on an agro-pastoral system (Koirala et al., 2012). The site's grazing area also overlaps with the habitat of several livestock-preying carnivores. Such resource sharing makes the ACA a suitable area for answering our research question about HWC.

Our study examined the different levels of HWC in the ACA using a socio-ecological framework and the correlates of conflict perception formation. We first investigated the determinants of depredation in the area, how its effects are distributed in the population, and whether those losses engender a higher perception of conflict. Afterward, we assessed whether high conflict perception translates into low support for conservation efforts. Our underlying assumption was that under significant HWC-induced losses, households curtail consumption and total welfare diminishes, both of which increase conflict perception and lower support for conservation. Last, we examined the relationships between recent events in increased livestock rearing, pastureland degradation, and increased conflict with social and economic factors at play in the region. Ultimately, we asked whether the current trajectory will shift under the business as usual. In doing so, we explored how HWC might develop in the future in light of social customs, market forces, and various HWC mitigation measures implemented by ACA authorities.

2. Material and methods

2.1. Study area

The ACA, located in Nepal's Trans-Himalayan region, includes LoManthang Rural Municipality (LRM) in the north of the ACA's Upper Mustang region, Gandaki Province, from 83° 50′ to 84° 20′ in the east and from 29° 5′ to 29° 20′ in the north. In the shadow of the Great Himalayas, with a barren, rugged terrain and subalpine climate, LRM covers 727 km^2 and has human habitation from 3500 to 4400 m above sea level (Fig. 1). The average annual precipitation is 200 mm, more than half of which falls as snow from October to April, and the average maximum and minimum temperatures are 26.8 °C and −5.8 °C, respectively. Encompassing approximately 583.9 km^2 of pastureland (Aryal et al., 2014a), LRM also comprises scanty subalpine vegetation, alpine pastures, and some planted orchards.

Agro-pastoralism, tourism, and seasonal business (hawking of herbal medicine and precious stones) are the region's three principal economic activities. Farmers grow oats, wheat, buckwheat, potatoes, and beans in a single crop-growing season between April and October as well as raise cows, horses, mountain goats, and yaks. Locals cultivate crops in the river valleys and use all accessible slopes of the surrounding mountains for pastoral grazing. Each year, livestock herders free graze in pastures at lower altitudes around the settlement for 3–5 months and relocate to higher-altitude pastures in the summer before returning for wintering in the settlement. Thus, each spring and summer, sites of livestock herding and the homes of carnivores spatially overlap (Werhahn et al., 2019). Major carnivores, including snow leopards (*Panthera uncia*), Himalayan wolves (*Canis lupus chanco*), brown bears (*Ursus arctos*), lynxes (*Lynx lynx isabellinus*), steppe polecats (*Mustela eversmanii*), and red foxes (*Vulpes vulpes*), prey on livestock and compete with humans for wild prey (Chetri et al., 2017, 2020), including crop-raiding herbivores such as Himalayan marmots (*Marmota himalayana*) and blue sheep (*Pseudois nayaur*), along with Tibetan argali (*Ovis ammon hogdsoni*), kiangs (*Equus kiang*), and Tibetan gazelles (*Procapra picticaudata*).

2.2. Data collection

The ACA Project's Well-Being Ranking Survey (ACAP, 2018), covering all 561 households in LRM, was used as a sampling frame. The sample was stratified into three levels according to the then village development committees. From each stratum, we randomly selected households using random number table- 50 for Chhonup, 35 for Chhoser, and 45 for LoManthang. We conducted a field survey from May 31 to July 6, 2019, and five surveyors in two teams conducted the household survey from June 1 to June 15.

Using a semi-structured questionnaire (SI 6), we collected information on respondents' socioeconomic and demographic characteristics (e.g. level of education, crop varieties grown, livestock holdings, land ownership, and sources of income), experiences with HWC (i.e., crop damage, human casualties, livestock predation, and attacks on sheds), wild animal diversity, and support for conservation. Open questioning was employed wherever possible to avoid leading respondents to give certain answers, and local guides were used to explain the technical terminology and animal species. Surveyors recorded all dialogues and clarified them immediately after each interview. We handled migration in the sample by using the nearest next household and absence by revisiting the household.

We conducted 30 key informant interviews, held three focus group discussions, and made seven visits to pastureland to supplement the household survey. Key informant interviews (KII) were selected to represent diverse interest groups, each stratum, and different levels of authorities (SI 7). For key informants, we selected local schoolteachers ($n = 3$), politicians ($n = 3$), CA management committee (CAMC) members ($n = 3$), nomadic pastureland herders ($n = 10$), ACAP field staff ($n = 4$), LRM's mayor ($n = 1$), LRM staff members ($n = 2$), ACA Jomsom office head ($n = 1$), and ACA head office staff ($n = 3$). Meanwhile, we held focus group discussions (SI 5), one for each stratum, with individuals from the ACA, CAMC, local youth clubs, LRM, local women groups (Aama Samuha), and local residents. The objectives of the discussions were to collect information on the status of HWC, any differences caused by conservation interventions, means of conflict

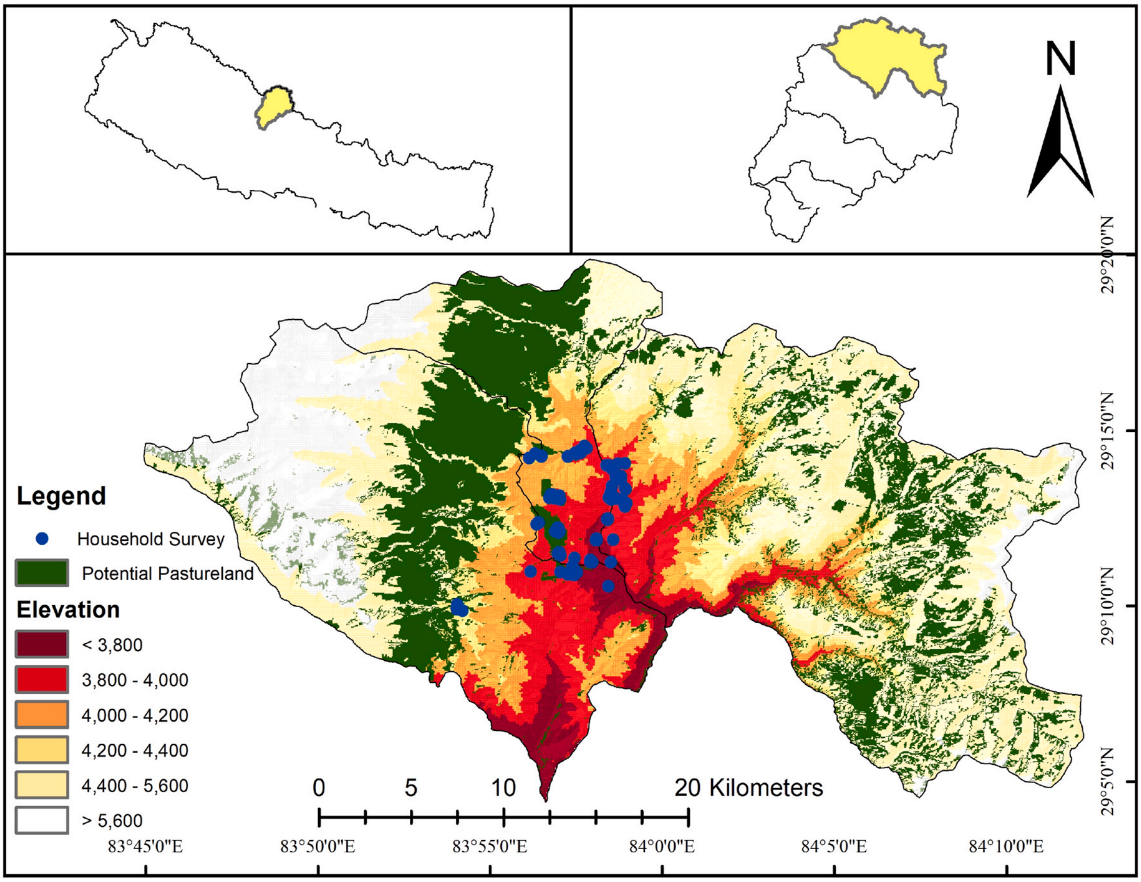

Fig. 1. Study area map showing elevation, potential pastureland in dark green (Uddin et al., 2015) and surveyed households (blue points). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

management, and livelihood strategies. The KII were conducted to verify information collected from the household survey and to get insight into the HWC issues. Quantitative data obtained from the field were coded and parsed using MS Excel and later analyzed in R 4.0.3 (R-CoreTeam, 2020) and Stata 16 (StataCorp, 2019).

2.3. Wildlife damage compensation mechanism

Nepal government's compensation guideline for wildlife damage (GoN/MoFE, 2018) maintains a list of problematic wildlife species (SI 8). The household which suffers from human injury and death, livestock depredation, and crop and property damage from the listed species can claim the compensation with the prescribed documentation. The mechanism itself is designed to thwart fraudulent claims and promotes a thorough process that includes veterinary certification, committee visits, and photographic evidence of carcasses (SI 3). The maximum possible valuations are set at a national level by the guideline and are insensitive to the local sensibilities, but the actual rates received by the distressed families vary area to area and are ad-hoc based on the budget available with the concerned local authority in a given fiscal year.

2.4. Empirical strategy and analysis

We employed three empirical frameworks in the study: Poisson-logit maximum-likelihood hurdle, binomial logistic, and ordered multinomial logistic regression models. The models were selected stepwise using information criteria viz. AIC (Burnham and Anderson, 2002). We have reported robust standard errors in the results to account for possible heterogeneity. In the depredation model, the depredation count of livestock is the response variable, which we modeled using Poisson error structure and checked for overdispersion and zero inflation. Due to overdispersion but a lack of zero inflation, we chose the hurdle model, and Vuong's test was used to compare the hurdle and Poisson models. In the second model, the shed attack model, our variable of interest (i.e., attacks on sheds) was 1 in the case of an attack and 0 if otherwise. We opted for a logit model, which we regressed with the different predictor variables (SI 4). We also checked for possible endogeneity through extended regression estimates. Last, in the third model, a multinomial ordered logit model, addressing perceived HWC, a dependent variable was used with an ordered factor at three levels—high, medium, and low—to measure HWC's intensity.

We collected information on the species and life stage (i.e., calf or adult) of livestock to categorize species into groups: cows, horses (i.e., mules and horses), mountain goats (i.e., sheep and mountain goats), and yaks (i.e., yaks, chauri, and jhokpa). Livestock prices were collected during key informant interviews and verified in focus group discussions. Depredation rate was calculated as the ratio of reported one year livestock depredation to the total livestock held that year. Since most of the depredation incidents were not reported to the conservation authorities, we used self-declared depredation counts from the household survey. We used herd characteristics, available livestock weight, proxy for shed location, and the interaction between predator diversity and herd size to explain the depredation head count in 2018. Snow leopards, wolves, and lynxes have been reported to target yak calves, horse calves, and mountain goats (Agarwala et al., 2010; Alexander et al., 2015; Farrington and Tsering, 2019), and herds with large juvenile populations and mountain goats typically increase yearly depredation (Sangay and Vernes, 2008). During night resting, yaks encircle their young, making them safer against depredation. Thus, the fraction of mountain goats and calves to the herd size variable captures this effect of having more adults in the herd. We expected available livestock biomass to increase yearly depredation by reducing the density of wild prey and increasing the relative abundance of livestock to carnivores (Oli et al., 1994; Wegge et al., 2012; Li et al., 2013; Suryawanshi et al., 2017).

During the survey, we asked households if any of the predator species listed (i.e., snow leopard, Himalayan wolf, lynx, red fox, and brown bear) had been sighted in the vicinity and if encounters had increased in the recent years. We reduced this richness matrix's dimension using principal component analysis, whose first component was used to create the predator richness metric. We positioned richness as a proxy for predator diversity, which by itself and in interaction with herd size was expected to increase the number of depredation events (Aryal et al., 2014a; Farrington et al., 2019). Added to that, considering that attacks on sheds by predators (i.e., "shed attacks") often result in multiple deaths and sometimes even mass slaughter (Chetri et al., 2019a), we expected shed defensibility to explain a portion of the yearly depredation. As a proxy for shed defensibility, we used shed light, which captured the effect of light continuously switched on for the whole night, and location, because 24-hr electricity is available only in more accessible sheds. Generally, sheds directly attached to houses or inside settlement areas have light, whereas sheds at a distance from the settlements and pastureland do not. Shed light thus also captured the effect of sheltering herds in relatively conspicuous sheds to defend against predators.

In the shed attack model, we modeled predators' attacks on sheds in the year surveyed using binomial logistic regression. We used the predator diversity metric, perceived habitat loss, herd size, herd size interaction with pastureland grazing, perception of recent changes in wildlife movement in vicinity, and having a shed with a roof (i.e., "shed roof") as explanatory variables. For one, because habitat loss reduces the availability of prey and increases the depredation of livestock (Pokharel et al., 2007; Shrestha and Wegge, 2008; Bhattarai, 2009; Chetri et al., 2019b), we used perceived habitat loss to account for changes in the natural habitat for local wildlife and asked respondents whether the local natural habitat had degraded in recent years. Perceived habitat loss was expected to correlate positively with the probability of shed attacks.

For another, the interaction between herd size and pastureland grazing accounts for the differences between shed attacks on local sheds and sheds in pastureland. Because carnivores have ample opportunities to attack free-ranging livestock during the day, most daytime attacks occur in pastureland, whereas nighttime attacks occur in sheds (Koirala et al., 2012; Kusi et al., 2019). Thus, we expected that interaction to decrease the number of shed attacks. Next, perception of increased human–wildlife interactions reflect the trend of increased animal movement in the vicinity. Together with predator richness that increased interaction increases the probability of shed attacks. Lastly, shed roof denoted the quality of sheds. Higher-quality sheds are expected to reduce shed attacks (Koirala et al., 2012; Farrington et al., 2019). Although we collected multiple variables of quality—shed light, fence, and presence of a guard—they were all either strongly correlated with location or lacked sufficient variance. Thus, we used only shed roof as a proxy for shed quality.

In the perceived HWC model, we used the ratio of annual depredation loss to income, encounters with wildlife, problems for agriculture caused by wildlife, the diversification of livelihoods, and the distance from the local conservation office as explanatory variables and controlled for respondents' age, gender, and level of education. The annual loss by depredation is depredated headcount in a year multiplied by the local price of the livestock. We calculated average annual loss for locality and livestock category by averaging the value over the surveyed household. The loss-to-income ratio captures the degree of depredation's impact on the household's resources available for consumption. If a household cannot replace depredated livestock, then the ensuing loss of production capacity reduces sources of future income (Ikeda, 2004), and severe loss results in an immediate curtailment in consumption. Privation induced by depredation was expected to increase the perception of HWC. The encounters with wildlife variable encompasses the psychological trauma of direct encounters with large carnivores and its impact on desirability of such fauna in the vicinity. For humans, direct encounters with large carnivores induce fear, insecurity, loss of sleep and focus (Alexander et al., 2015; Acharya et al., 2016; Manoa et al., 2020). Considering the undesirability of such negative interactions, we expected direct encounters with wildlife to increase perceived HWC.

The problems in agriculture caused by wildlife, a dichotomous variable capturing the effect of crop damage was expected to have a direction and mechanism similar to those of the loss-to-income ratio. Diversification in CA-based livelihoods, indicating whether any household members engage in any occupations directly related to the CA, captures the effects of both diversification in livelihoods beyond animal husbandry and partaking in business opportunities created directly by the CA. We generated that variable by checking whether respondents' sources of income were related to the CA, with the underlying hypothesis that households with diversified livelihoods are more willing to accommodate wildlife-induced losses in their formation of conflict perception and have positive attitudes toward supporting conservation (Thapa Karki, 2013; Mir et al., 2015).

We computed the least topographic surface distance from the household to the local compensation disbursing office using the topoDistance package (Wang, IJ, 2020) and elevatr package (Hollister et al., 2020) in R. If any costs of conservation messaging were associated with distance, then we expected that households near the conservation office would have greater awareness of the importance of wild flora and fauna. Based on the premise that awareness begets tolerance, distant households are more likely to be less tolerant of depredation and perceive greater conflict than nearby households. Assuming that conservation awareness indeed changes with distance, we expected increased distance to increase the severity of conflict perception. Last, we also controlled for three socio-demographic factors—literacy, age, and sex—known to affect attitude toward wildlife (Agarwala et al., 2010; Lischka et al., 2018; Hacker et al., 2020).

3. Results

3.1. Respondents' characteristics and livelihood strategies

Slightly less than three quarters of the respondents (72.31%) were 31–60 years old, while about a fifth were above 60 (19.25%). Most

Table 1
Descriptive table on selected variables.

Variable		Frequency (%)/Range (Median)
Gender	Female	46 (35.38)
	Male	84 (64.62)
Age (years)	≤30	11 (8.46)
	31–60	94 (72.31)
	≥61	25 (19.25)
Literacy	Illiterate	86 (66.15)
	Literate	44 (33.85)
Income diversification	Yes	105 (80.77)
	No	25 (19.23)
Seasonal migration	Yes	117 (90.00)
	No	13 (10.00)
Annual household income ('000 NPR)		125–500 (332.5)
Livestock holding (heads)		0–238 (9)
Value of livestock ('000 NPR)		0–5875 (45)
Previous year depredation (heads)		0–22 (1)
Previous year depredation ('000 NPR)		0–350 (5.5)
Predator attack in shed	Yes	59 (45.38)
	No	71 (54.62)
Shed light	Yes	58 (44.62)
	No	72 (55.38)
Shed roof	Yes	71 (54.62)
	No	59 (45.38)

respondents were men (64.61%) and illiterate (66.15%) (Table 1); approximately a third (30%) had informal education, and only 3.85% had some form of schooling. Buddhism was the majority religion (93%), followed by Hinduism (7%). The average annual income, NPR 371903 (US $3381) overall, was highest in LoManthang (US $4399), followed by Chhoser (US $3169) and Chhonup (US $2613). The migration of households to lower altitudes in winter was typical (90.00%).

The data revealed that nearly all households (95.4%) depend on agriculture, and many had diversified their income (80.77%) with livestock trading, daily wage labor, seasonal hawking, and/or personal businesses. Most households (95.38%) own land, with an average landholding of 0.57 ha, and most of their agricultural land (86.2%) is irrigated to cultivate a single yearly harvest of wheat, oats, buckwheat, potatoes, mustard, and/or beans. Few households (9.3%) rely entirely on the CA for fuel and animal fodder, whereas most (83.05%) use private land along with the CA. Most of the households own livestock (92.3%), often cows (81.5%), although mountain goats are held in the largest numbers (SI 1). Cow owners generally feed their livestock in stalls, whereas most goat and yak herders use pastureland. Approximately a third (36.67%) of the livestock-holding respondents reported using pastureland as their primary grazing area, although only a fourth of households (26.08%) employ watchers for grazing.

3.2. Livestock depredation and crop damage

About two thirds of respondents (67.69%) reported facing some sort of agricultural problem caused by wildlife, with livestock depredation (63.3%) greatly overshadowing crop-raiding (31.45%). However, crop damage, predominantly due to Himalayan marmots during the summer cropping period, was not substantial, and no human casualties due to wildlife were reported. By contrast, about two thirds of the households owning livestock (64.12%) faced at least one depredation incident from 2013 to 2018. Altogether, 77 households lost 1634 heads of livestock in a 5-year period (2013–2018), and 67 lost 427 livestock in 2018 alone. Of the 3.56 heads lost per livestock-holding households, mountain goats accounted for 63.5% of total depredated livestock weight (SI 2). Despite similarly sized depredation-affected households (36 vs. 32), concentrated ownership of mountain goats compared with cows (106 vs. 41) resulted in a higher fraction of depredation for households keeping mountain goats, most of which (87.8%) had suffered lost at least one goat to depredation during the 5-year period. The depredation rates of mountain goats in Chhonup, Chhoser, and LoManthang were respectively 7.8%, 10%, and 3.8% of each stratum's total livestock, whereas horses had the lowest depredation rate (0.19%). Geographically, depredation was high in the northeast region of the LRM.

Average annual loss due to livestock depredation was NPR 50 358 (US $457.80) per livestock-owning household, while the total economic loss in 2018 was NPR 6043000 (US $54,936.40). Mountain goats, as the chief driver of economic loss, accounted for 87.1% of all loss. Between the lowest and highest income quintiles (8.5 vs. 68.2), the number of livestock held differed by a factor of eight, and the value of livestock holding increased proportionally. The wealthiest quintile suffered a loss of more than a fifth of annual income (23.28%) due to depredation, compared with a loss of 3.5% in the poorest quintile (Table 2).

3.3. Dimensions of depredation

In the depredation model addressing annual depredation (Table 3), shed defensibility and herd biomass strongly explains the model's hurdle portion ($p < 0.01$). Once a hurdle portion of model is overcome, herd characteristics ($p < 0.01$), herd biomass ($p < 0.01$), and the interaction between herd size and predator diversity ($p < 0.05$) become important correlates (Table 3). Importance of herd characteristics to depredation mechanism was supported by KII with the herders; because predators in the area do not generally attack large, healthy animals, herders leave horses, yak, and jhokpa on pastureland without oversight for several

Table 2
Average depredation loss across income quintiles.

	Yearly Income ('000) NPR	Value of livestock ('000) NPR	Herd size N	DHS (%)	Value of depredation to income (%)	livestock (%)
Overall	319.98	844.11	33.06	7.27	12.46	3.41
Quantile group average						
Poorest	194.0	325.1	8.50	5.65	3.50	1.50
Poorer	267.8	521.5	20.9	9.28	10.81	4.18
Middle	327.5	653.0	32.2	6.18	11.66	3.40
Richer	364.4	965.8	35.5	6.64	13.04	3.08
Richest	446.2	1755.2	68.2	8.59	23.28	4.87

DHS: Depredation to herd size.

Table 3
Minimum adequate model (AIC) for annual depredation headcount.

		Depredation head count in 2018 Zero hurdle model (Binomial with Logit link)	Count model (Truncated Poisson with log link)
Fraction of mountain goat and calves to herd size		−0.911 (1.191)	2.413*** (0.307)
Log (total livestock weight)		2.503*** (0.632)	0.475*** (0.104)
Shed light (Shed defensibility and location proxy)		−4.015*** (0.954)	−1.008 (0.639)
Predator diversity		0.555 (0.600)	−0.074 (0.216)
Interaction between herd size and predator diversity		0.007 (0.013)	0.003** (0.002)
Constant		−15.051*** (4.286)	−3.805*** (0.813)
Observations		120	120
Wald chi^2 (df = 4)		29.37***	
Vuong test	z-statistics	H_A	p-value
Raw	−2.329	Hurdle > Poisson	0.009
AIC Corrected	−1.292	Hurdle > Poisson	0.098
BIC Corrected	0.153	Poisson > Hurdle	0.439

Robust SE in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

weeks at a time, and when these animals scatter to find grass in the pastureland, they have to be searched for when returning them to the village. Mountain goats, however, graze openly but are corralled at night. Keeping all else constant, shed defensibility decreases the incidence of depredation by 98%, whereas a unit increase in the fraction of mountain goats and calves to herd size increases depredation by 11-fold.

Unlike in that model, predator diversity in the vicinity is significant ($p < 0.1$) in the shed attack model (Table 4). Perceived habitat loss positively increases the odds of shed attacks 6.37-fold versus sites where habitat loss is not perceived. Total livestock size also increases the odds of shed attacks, whereas the interaction of herd size with pastureland grazing decreases the attacks ($p < 0.05$). A perceived increase in recent wildlife interactions is positively related to attacks on sheds ($p < 0.05$). Shed quality catch-all, roof in the shed, is negatively related to attacks on sheds but not significantly. However, shed roof has a statistically different outcome on livestock loss ($t = 10.97$, $df = 118$, $p < 0.05$) and shed attacks ($\chi^2 = 49.34$, $df = 1$, $p < 0.05$). Thus, the quality of sheds, given the combined effect of light, a roof, and fencing, significantly affects livestock loss ($t = 8.15$, $df = 118$, $p < 0.05$) and shed attacks ($\chi^2 = 84.22$, $df = 1$, $p < 0.05$).

In winter, herders bring livestock into the village, and natural prey is less abundant due to reduced forage availability in pasturelands covered by snow. Livestock loss varied significantly not only from season to

Table 4
Shed attack model.

	Predator attack on shed in 2018 (Binomial logit model)		
	(1)	(2)	(3)
Predator diversity	1.146* (0.601)	1.274** (0.628)	1.242* (0.680)
Perception of habitat loss in vicinity	1.498** (0.684)	1.702** (0.700)	1.852** (0.749)
Herd size	0.333*** (0.088)	0.335*** (0.102)	0.364*** (0.136)
Interaction between herd size and pastureland grazing	−0.203*** (0.072)	−0.211** (0.084)	−0.269** (0.133)
Perception of increase in recent wildlife interactions		1.620** (0.649)	1.658** (0.741)
Presence of roof in shed			−1.719 (1.455)
Constant	−4.079*** (0.887)	−4.626*** (1.115)	−3.351*** (1.216)
Observations	120	120	120
LR chi^2	23.42***	24.37 ***	26.24***
Log likelihood	−39.519	−36.323	−34.941
Pseudo R^2	0.555	0.563	0.579

Robust SE in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

season ($\chi^2 = 56.88$, $df = 1$, $p < 0.05$), with the greatest amount occurring in winter, but also by location, with more occurring in pastureland and fewer in sheds ($\chi^2 = 36.19$, $df = 1$, $p < 0.05$). Loss per pastureland-grazing household ($n = 44$) was 338.75 kg (i.e., depredated livestock weight) but only 43.5 kg per stall-feeding household ($n = 76$).

3.4. Attitudes toward HWC and mitigation efforts

The mortality of livestock due to disease and accidents was negligible in the ACA. Snow leopards were the leading cause (62.6%) of livestock depredation, followed by Himalayan wolves (16.4%); nevertheless, 95% of respondents expressed positive attitudes toward conservation, including of large carnivores, mostly due to religious beliefs (60%)—locals largely adhere to Vajrayana Buddhism, which detests the killing of wildlife—followed by aesthetics (18%) and wildlife's value in promoting tourism (17%). Approximately one-fourth of respondents (26.15%) associated wild animals roaming around settlement areas with a diminished natural habitat and reduced food availability - by comparison, 43.07% of respondents identified food availability as the sole cause. In our KII, most nomadic herders were concerned about the decline in grass in pasturelands and generally reported a recent uptick in mountain goat and yak rearing.

In the HWC perception model (Table 5), the loss-to-income ratio and direct encounters with wildlife are strong predictors of perceived HWC ($p < 0.01$). The diversification of CA-based livelihoods is negatively correlated to conflict perception but not significantly. Even so, households that engage in such diversification statistically differ in their formation of conflict perception from ones that do not ($\chi^2 = 12.616$, $df = 2$, $p < 0.05$). Although literacy is not significant in the model, it is a crucial determinant of knowledge about livestock insurance ($\chi^2 = 116.95$, $df = 1$, $p < 0.05$). Whereas most of the literate respondents were aware of the insurance program, all illiterate respondents were not.

LRM has been within the ACA for the past 36 years, and the conservation authority involved locals through powerful CAMC bodies, which have key roles in conservation, monitoring, training, and compensation activities. Furthermore, the ACA has generated trust by providing non-environmental public goods. In our fieldwork, respondents frequently contrasted the ACA Project's year-round health facility to a government-owned health facility that closes every winter. Respondents were primarily satisfied (60%) with training and awareness but dissatisfied with compensation (65%). Generally, herders in pasture did not count heads every day and thus sometimes remained

Table 5
Perceived seriousness of HWC model.

		Perceived seriousness of HWC (Multinominal ordered logit)		
		(1)	(2)	(3)
Y ≥ Medium		−2.553*** (0.793)	−0.804 (1.172)	−0.785 (1.189)
Y ≥ High		−7.873*** (1.198)	−6.374*** (1.489)	−6.434*** (1.502)
Ratio of yearly depredation loss to income		6.838*** (2.438)	7.144*** (2.225)	7.647*** (2.284)
Encounter with wild life		3.893*** (0.861)	4.020*** (0.891)	4.051*** (0.908)
Wildlife problems in agriculture		0.557 (0.655)	0.589 (0.669)	0.759 (0.686)
Conservation area based livelihood diversification		−0.965 (0.596)	−1.039 (0.633)	−1.004 (0.633)
Distance from local conservation office (Log)		0.131 (0.127)	0.128 (0.130)	0.136 (0.128)
Literacy	Literate	0.159 (0.527)	−0.084 (0.640)	−0.001 (0.645)
Age (Base category ≤30 yrs)	31–60 yrs		−1.949** (0.792)	−1.680** (0.795)
	≥60 yrs		−1.439 (0.973)	−1.196 (0.982)
Sex	Male			−0.731 (0.513)
Observations		130	130	130
Log likelihood		−62.657	−59.945	−59.102
Pseudo R^2		0.491	0.513	0.519
Wald chi^2		78.83*** (df = 6)	83.96*** (df = 8)	82.77*** (df = 9)

Robust SE in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

unaware of depredation incidents for weeks. When depredation occurred in opens without herders in vicinity, identification of predator and finding carcasses were difficult. Furthermore, generation of photographic evidence in pastures, generally lacking electric facility to charge devices, caused another snag in the documentation preparation. On the opposite end of the spectrum, if a household lost a single cow calf but retained a portion of the carcass, the necessity of CAMC's team-visit with a veterinarian complicated and prolonged the application process. The compensation mechanism worked best when a predator entered a shed, slaughtered many animals, and left. In that scenario, the household had both evidence and sufficient motivation to pursue the time intensive scheme. In that way, the compensation scheme provides a hedge to depredation risk but only to the right tail of the distribution.

Nevertheless, depredation compensation is a strong indicator of perceiving that the CA offers high benefits. Meanwhile, high conflict perception is informed primarily through depredation intensity. Most highly depredated households that reported high conflict also perceived the CA's high benefits if they had received compensation (SI Fig. 1). By contrast, a low perception of the CA's benefits is primarily represented by households that suffer from a mid-range level of depredation but have not received any compensation.

4. Discussion

4.1. Dynamics of depredation

Livestock constitutes a major component of wealth (Oli et al., 1994; Sherchan, 2019; Chetri et al., 2019a) in trans-Himalayas of Nepal and is generally, pricier than livestock reared in Nepal's hills and plains. More affluent households in the region tend to have more wealth in livestock, which again contrasts other geographical regions of Nepal. Thus, together with livestock, tourism directly affects most households and the local standard of living (Tiwari et al., 2020). Herds that graze in pastureland overlapping the habitat of wild fauna, including carnivores, can more often fall prey to depredation, which in economic terms is the direct loss of a productive asset that has to be replaced to maintain the earlier standard of living (Namgay et al., 2014). That conflict due to resource sharing, a common one in pastoralist societies living near CAs (Shrestha et al., 2008), is distinct from other forms of HWC due to its regularity and, as such, can intensify over time amid a lack of mitigation measures.

HWC, approximately determined by human and wildlife behaviors, results from the context shaping those behaviors. Lischka et al. (2018) socioecological system (SES) framework stresses explicitly acknowledging the host of external and internal factors operating within social and natural ecological systems in order to understand HWC. Because systems overlap and share feedback among actors therein, a complex web of interactions informs the HWC, and both the yearly depredation model and shed attack model exemplify those types of interactions. For one, herders choose what kind of livestock to own based on market demand, whereas predators select prey based on their relative body size. The first behavioral decision has increased the stock of mountain goats in the region, whereas the second has increased the depredation of mountain goats and calves of other animals (Oli et al., 1994; Wegge et al., 2012; Suryawanshi et al., 2017; Chetri et al., 2019b). The herd characteristic variable neatly captures those two sets of interaction and is a strong predictor of yearly depredation and shed attacks. Overall, our statistical results reflect SES-type interaction. In particular, larger herds consisting primarily of mountain goats, grazing in pastureland overlapping with large carnivores' natural habitats and are kept in sheds that are difficult to defend, are more vulnerable to depredation. Additionally, shed attacks are high in areas with diverse predators, degraded natural habitats, and recently increased human–wildlife interactions.

Our reported depredation rate (9.03% of herd size) is larger than previous findings from the Himalayas of 1.0%–4.0% (Oli et al., 1994; Wegge et al., 2012; Aryal et al., 2014a; Chetri et al., 2019a) but comparable to Alexander et al. (2015) finding of 12.5%, which included disaster and disease along with depredation. A possible reason for the difference is the recently increased livestock stocking in pastureland (Fig. 3). The higher aggregate area-wide economic loss detected in our study compared with prior works has two possible explanations: our depredation rate was higher and our livestock prices differed. Although some studies have involved pricing depredated livestock with a heavy discount on then-prevailing market prices, we argue that depredated livestock is a foregone asset that could have been sold at prevailing market prices. All livestock owners are price-takers (i.e., no single owner can corner the market), and that replacing the lost animal would come only at the market price. Following those assumptions, we used prevalent prices erring on the conservative side.

4.2. Perceived conflict and environmental degradation

The view of HWC as a transactional dispute to be resolved solely by establishing shared interest through compensation fails to acknowledge deeper SES-type dynamics. Madden and McQuinn (2014) conflict framework divides HWC into three levels: the tangible dispute, the underlying conflict that adds meaning to the dispute beyond immediately observed facts, and the identity conflict, which involves values and beliefs at the core of at least one party's identity. In the study area, depredation and shed attacks create disputes, and households and herders can directly observe the material loss. If losses are regular and conservation programs do not provide sufficient compensation, then higher conflict perception can take root. Nearly all households that perceived high HWC in our study were in the highest quartile of depredation loss from 2013 to 2018, and that pattern is reflected in our perceived wildlife conflict model, in which economic loss and direct encounters with wildlife are the strongest predictors of conflict perception.

However, degradation of pastureland by overstocking forms the underlying conflict in the region. The region's comparatively affluent families are engaged in commercially raising mountain goats (Fig. 2), whose primary buyers are families in urban Nepal seeking goats for slaughter during Dashain, the most significant of yearly Hindu festivities. The commercial nature of mountain goat and yak rearing is reflected by average herd size; cow owners rear an average of 4.38 cows, whereas mountain goat owners and yak owners raise an average of 82.35 goats and 18.54 yaks, respectively. Continuous growth in per-capita income in Nepal in the last decade has increased household purchasing power and greatly intensified the demand for meat (GoN/MoF, 2020). Similarly, as tourism in ACA has grown, a sustainable consumer base has formed for mountain goat meat, traditional yak cheese (*chhurpi*), yak butter, and yak tail.

Herders have responded to such growth in demand by raising more yak and mountain goats. In the span of 8 years (2011–2018), cow, buffalo, horse, and sheep rearing remained at roughly the same level, whereas that of mountain goats increased by threefold, from 19 992 to 65 939 (GoN/MoALD, 2018), and yak by about one and half-fold, from 4145 to 6790, in the Mustang district (Fig. 3). LRM and adjoining the then VDCs of Charang, Surkhang, and Ghami, which host continuous pastureland, are the district's primary mountain goat rearing sites (Aryal et al., 2014a), and the district's trend with mountain goats closely reflects the local pasturelands' increasing livestock pressure.

Such expansion in yak and mountain goat populations has direct consequences for the pastureland's health. Perhaps above all, already low productivity in the Trans-Himalayan region (Paudel and Andersen, 2013) has been further reduced by overgrazing (Pokharel et al., 2007). DiTomaso (2000) has shown that overgrazing changes the composition of plants and introduces invasive species into pasturelands, while herders' use of dried animal dung for cooking fuel effectively cuts nutrient recycling. Earlier studies (Aryal et al., 2014b; Tiwari et al., 2020) in the Trans-Himalayas have revealed livestock density exceeding capacity degrades the ecosystem of pasturelands. Unsupervised rearing of yaks and the fact that the yak forages for a specific type of grass, which is also an essential dietary component of blue sheep, means strong interspecies competition (Shrestha et al., 2008), thereby resulting in the lower recruitment of blue sheep in the region. This has repercussions for the ecosystem's carrying capacity to support healthy snow leopard population. The combination of a low availability of natural prey and higher livestock density in pastureland encourages depredation (Devkota, 2010; Kusi et al., 2019). Change in carnivores' behavior induced by livestock availability also carries over to the seasonality of depredation (Chetri et al., 2019a). Predators respond to that lack of both natural prey and livestock in pasturelands during winter by moving to lower altitudes and increasing their frequency of shed attacks near the

Fig. 2. Change in herd size and herd composition with income quintiles. The richest quintile group in the study not only holds a significantly larger herd size (approximately seven times Q1) but a herd that consists primarily of mountain goats (85.1%), and Yak; engaged in livestock trading and yak milk processing.

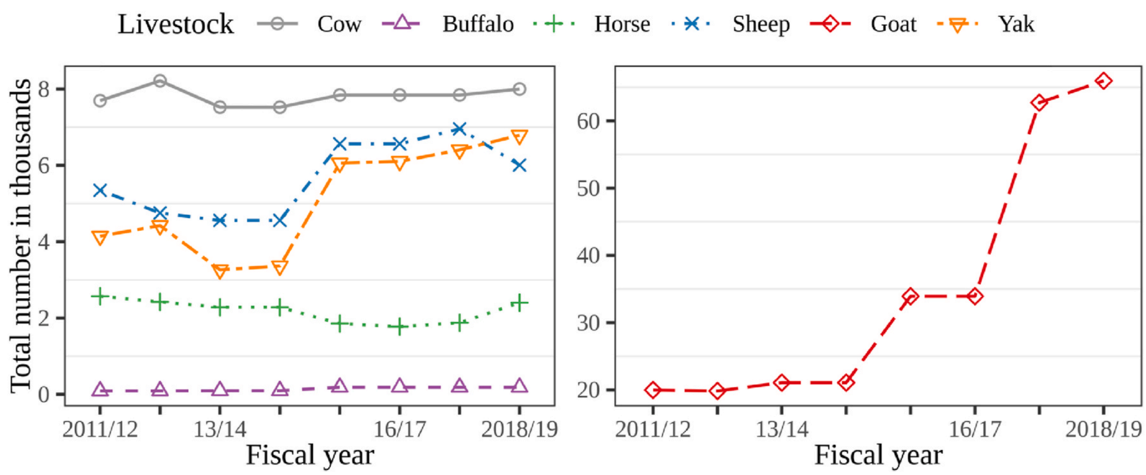

Fig. 3. Livestock holding by families in Mustang district (2011–2018). The years are based on Nepalese fiscal year which starts from mid-July. This series is constructed from multiple years of agricultural statistical information published by (GoN/MoALD, 2018).

settlements.

The deepest level, or identity-based part of the conflict, is the decline of transhumance pastoralism (Tiwari et al., 2020). The locals' strong roots in transhumance pastoralism form an integral part of their identity, and they consequently do not sell physical assets viz. land and house to outsiders. That selling restriction affects herd ownership since the pastureland areas are designated according to the village where one has a house. A decline in households' ownership of livestock does not necessarily imply less livestock in pasturelands, however, but a shift in ownership among neighbors. The herds' maximum possible sizes are constrained by the financial capacity to invest and the availability of labor in the households. With no ecological consideration in decision-making about herd size at the household level, strong market prices for mountain goats and yak products have continually increased the population of those animals (Fig. 3) in the community's pasturelands.

4.3. Conflict mitigation

Proper conflict resolution seeks to address all layers of the conflict. The three corners of the intervention triangle—process, relationship, and substance (Walker and Daniels, 1997; Madden et al., 2014)—aim to go beyond immediate dispute resolution by recognizing the ability of a sound process and positive relationships to address underlying and identity-based conflicts. The long span of conservation program, substantial grassroots work, and the supply of various public goods have raised awareness about conservation and biodiversity, and engendered favorable opinions about the ACA Project. Such awareness could explain the non-significance of distance in the conflict perception model.

Despite the strong relationship with the ACA Project, locals were unsatisfied with the process and substance aspects of the intervention triangle and especially criticized the authority's serpentine process and the size of compensation. Proponents of such compensation schemes have advocated the need to compensate locals for losses by awarding globally valued ecological goods with a poor local cost–benefit ratio (Dickman, 2010; Dickman et al., 2011; Karanth et al., 2012; Morzillo and Needham, 2015; Ravenelle and Nyhus, 2017). By contrast, detractors have decried the possibility of encouraging humans in and around protected areas (Bulte and Rondeau, 2005; Watve et al., 2016), the unsustainability of the compensation process, the likelihood of arduous bureaucratic mechanisms, and the limited ability of compensation to generate support for conservation (Madden, 2004; Mir et al., 2015; Nyhus, 2016; Karanth and Kudalkar, 2017).

The compensation process is especially problematic for depredation in pasturelands. Our results as well as recent compensation records (SI 9) show that most people who have received compensation have experienced significantly high depredation. Such a scheme's socioeconomic distribution implies that only well-endowed herders, who also happen to be relatively rich in the local community, receive compensation. The average household, however, with a smaller herd suffering from a medium level of depredation, is less likely to be compensated. Thus, the program hedges the risk of the small group of wealthy, market-driven farmers who are actively engaged in livestock trading and highly dependent on the community's pasturelands.

The compensation rate compounds with that complicated procedure. The official rate for the yak is less than one-fourth of its market price (SI 8), and the annual compensation budget of the ACAP's local office is insufficient to cover yearly losses. That insufficiency of funding means that a household may not receive standard rates even when being compensated (SI 9). The rates, originally designed for large carnivores' attacks on livestock in the plains, thus fail to recognize the high value of livestock reared in the mountains. Furthermore, the current compensation mechanism fails to differentiate negligence from genuine misfortune; a herder lost all 104 goats in two consecutive nights (Chetri et al., 2019a). At current rates of compensation, such an incident can cause irrevocable financial ruin for herders.

Compensation alone fails to address the underlying conflict shaped by the degradation of pastureland. Reports of declines in the quality of pastureland (Pokharel et al., 2007; Aryal et al., 2014a) should be used by authorities to adopt scientific practices for pastureland management (Pretty et al., 2003; Nandy et al., 2006; Pokharel et al., 2007; Roche et al., 2015; Sharma, 2019) that allow for regenerating pastureland, raising livestock sustainably, and healthy natural prey base. Local authorities should recognize the decline of pastureland quality, commercial livestock rearing therein, and distributional aspects of the compensation program. Without recognizing the region's SES interaction or introducing controlling measures based on scientifically computed yearly grass yields, a future decline in HWC is a distant possibility.

The ACA Project has shown both the motivation and know-how to do so. Programs for improved sheds and the installation of focus-lights are steps in the right direction. Our results also show the importance of shed quality and light to reduce shed attacks and livestock death. Recently, ACA Project introduced a total ban on firewood and started providing subsidized liquefied petroleum gas to stop the herders' exploitation of regulatory loophole, because herders were removing bark from trunks to kill trees so that they could legally cut them for firewood. Similarly, medicinal plant collection in the region is regulated by quotas. However, judicious scientific practices in pastureland management have not been introduced.

The cross-sectional nature of data limited our study. Alternatively, repeated cross-sections or panels would have accurately captured the region's livestock dynamics and associated changes. Beyond that, our arguments highlighting pastureland degradation can be bolstered by field-based ecological data on pastureland vegetation. Such a vegetation time series would establish the effect of climate change and grazing on pastureland's sustainability. Moreover, predator and prey habitat analysis in the region that accounts for HWC influenced by climate change can help to predict future shifts in HWC in the region. Last, our definition of *income* (i.e., expenditure plus savings minus loans) does not capture all sources of income. The definition might have caused underreported incomes across all households. Even so, it would not alter the prime thrust of this article's arguments. Herders' stickiness to occupational change is an essential determinant of future conflict and sustainable livelihood in the region. Future studies on occupational change vis-à-vis in relation to transhumance pastoralism would address the gap.

5. Conclusion

Socio-ecological interactions are important determinants of depredation leading to HWC. Increased livestock stocking, pastureland degradation, and habitat loss amplify HWC in the Trans-Himalayan region of Nepal. Depredation engendered economic losses, and predator encounters have driven conflict perception, while the diversifications in livelihood and socio-economic characteristics have moderated that perception. The promotional value of tourism, religious beliefs, and non-monetary contributions by conservation authorities have all contributed to a positive outlook on conservation. Compensation mediates higher conflict perceptions towards the larger perceived benefits of the conservation program, whereas a lack of compensation when facing depredation reduces the perceived benefits. Current conservation practices are not conducive to reducing the existing level of HWC and require policy revision and implementation. Future conservation planning should incorporate sustainable pastureland management, streamlined compensation mechanism and the diversification of local livelihoods to integrate effective participatory conservation practices.

Credit author statement

Tika Ram Poudel: Conceptualization, Methodology, Investigation, Data Curation, Formal analysis, Software, Visualization, Writing – Original Draft, Writing – Review & Editing.: Prakash Chandra Aryal: Conceptualization, Methodology, Writing – Review & Editing, Supervision, Project administration.: Resham Thapa-Parajuli: Formal analysis, Software, Supervision.: Arjun Thapa: Conceptualization, Supervision.: Shailendra Kumar Yadav: Funding acquisition, Data Curation.: Manab Prakash: Conceptualization, Methodology, Data Curation, Formal analysis, Software, Visualization, Writing – Original Draft, Writing – Review & Editing.

Funding

This research work was partially funded by the National Trust for Nature Conservation (NTNC - ACAP).

Availability of data and material

Under reasonable request, authors will provide data used to generate statistical analysis in the paper.

Code availability

Under reasonable request, authors will provide code used to generate statistical analysis and plots in the paper.

Ethics approval

ACAP reviewed the research proposal and provided permission for the fieldwork inside the conservation area.

Consent to participate

Data generation was done after surveyors explicitly got both verbal and written consent from survey participants.

Consent for publication

We all authors consent for publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research work was partially funded by the National Trust for Nature Conservation (NTNC - ACAP). ACAP provided permission and assistance during the fieldwork. We thank ACAP's conservation officers, LoManthang Rural Municipality's administration and community people for their time and the following individuals for field assistance: Rishi Baral, Santosh Sherchan, Niranjan Rupakheti, and Shiva Gawali. We are grateful to late Dr. Man Kumar Dhamala, Ramakanta Sharma, Badri Baral, Diwas Sapkota, Dipak Khadka, Sandesh Neupane, Bishal Sharma, Pratik Bajracharya, Ramesh Lamichhane, and Pramananda Rajbanshi for their help in various stages. Feedbacks from Uttam Babu Shrestha (GIIS), Bharat Babu Shrestha (CDB, TU), Mani Nepal (SANDEE/ICIMOD), Shashank Poudel (Cornell CALS), Sovit Subedi (Asia Foundation), and Chandramani Aryal (PKC, TU) were helpful on polishing the final manuscript. Error and omissions, if any, are ours. We would like to thank anonymous reviewers for their insightful comments and suggestion which helped us to polish the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2022.114763.

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