



Human–carnivore coexistence in Qomolangma (Mt. Everest) Nature Reserve, China: Patterns and compensation



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ABSTRACT

Livestock depredation by large carnivores is frequently reported in Qomolangma (Mt. Everest) National Nature Reserve, Tibet Autonomous Region of China. Seeking to minimize conflicts, we assessed depredation patterns and ways to upgrade the compensation program. We gathered 9193 conflict records over 2011–2013 to determine the extent and tempo–spatial patterns of the depredation. We interviewed 22 local officials and 94 residents to learn their views on depredations and to assess the adequacy of compensation. Data showed that wolves (*Canis lupus*), lynx (*Lynx lynx*), and snow leopards (*Panthera uncia*) were the major livestock predators. Total livestock loss accounted for 1.2% of the entire stockholding ($n = 846,707$) in the region. Wolves and lynx tended to take sheep and goats, whereas snow leopards favored yaks and cattle in relation to their proportional abundance. Predation mostly occurred in March through July. Livestock depredation by all predators when combined was best explained by terrain ruggedness and density of small- and large-bodied livestock. Temporal and spatial predation patterns varied among carnivores. Most respondents (74%) attributed depredation causes to an increase in carnivore abundance. Only 7% blamed lax livestock herding practice for predation losses. Five percent said that predation was the result of livestock population increases, while 11% had no idea. The compensation scheme was found to be flawed in all aspects—predation verification, application procedure, compensation standard, operational resource allocation, making payment, and other problems. To enhance management for human–carnivore coexistence, we recommend a problem-oriented, integrated, adaptive approach that targets the complex social context of the conflict and addresses the interconnected functions of decision-making process.

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1. Introduction

Human–carnivore conflict is a worldwide conservation concern that challenges diverse societies' commitment to coexist in harmony with wildlife (Treves and Karanth, 2003). Conflicts appear to be on the rise in many areas, often resulting from human population growth and expansion, wildlife habitat loss and alteration, and, in rare instances, carnivore recovery (Dar et al., 2009; Inskip and Zimmermann, 2008; Pettigrew et al., 2012). Living close to large carnivores can impose significant costs on local residents (Dickman, 2010). Financial loss incurred by livestock depredation is but one, particularly in regions with weak economies and where pastoralism is the dominant livelihood (Jackson, 2015). The perceived and actual threats of livestock depredation can cause intolerance of large carnivores, sometimes resulting in retributive persecution and extirpation (Dickman, 2010; MacLennan et al., 2009).

These negative attitudes and behaviors undermine carnivore conservation and threaten long-term viability of many endangered carnivore species such as snow leopards (*Panthera uncia*, Bagchi and Mishra, 2006; Jackson, 2015; Li et al., 2013). Minimizing conflicts is thus critical to large carnivore conservation. Effective management strategies to conserve species require adequate understanding of the ecological and social underpinnings of the human–carnivore interaction (Bagchi and Mishra, 2006; Thirgood and Redpath, 2008; Thorn et al., 2012).

Livestock depredation by large carnivores is frequently reported in the Himalaya region (Ikeda, 2004; Jackson et al., 1994; Oli et al., 1994; Sangay and Vernes, 2008; Suryawanshi et al., 2013; Wegge et al., 2012). The Qomolangma (Mt. Everest) National Nature Reserve (QNNR) in Tibet Autonomous Region (TAR) is no exception (Jackson et al., 1994; Jackson, 1998). This area is home to large carnivores such as the snow leopard, wolf (*Canis lupus*), and Eurasian lynx (*Lynx lynx*). To remunerate local people for livestock and crop damage by wildlife, a government-funded compensation scheme was adopted for trial implementation in 2006 and has been formally put into effect since 2010. Yet the QNNR's inaccessibility and harsh environment—it is the

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highest protected area in the world—have meant that little information is available about human–carnivore conflicts and the effectiveness of the compensation program. Hence, we conducted the first landscape-level, systematic analysis of human–carnivore conflicts in QNNR. First, we described the structure and workflow of the compensation program, analyzed the extent and characteristics of carnivore predation on livestock, and showed temporal and geographical patterns. Second, we analyzed local perceptions about trends in and causes of livestock depredation, and we identified obstacles to effective implementation of the compensation scheme. Lastly, we offered strategic recommendations to foster human–carnivore coexistence that may be applicable to other regions.

2. Material and methods

2.1. Study area

Located in the southwest of TAR, China, the Qomolangma National Nature Reserve (QNNR; 27°48' N–29°19' N and 84°27' E–88°23' E) was established in 1989 to protect the wildlife and ecosystems along the border of China and Nepal (Fig. 1). The reserve is 33,814 km², centering on the world's highest peak, Mt. Everest. Altitude is 1440 m to 8844 m. Average annual temperature is 2.1 °C and total annual rainfall reaches 270.5 mm. About 81 mammal species, 342 birds, 29 amphibians and reptiles, and 8 fishes inhabit the reserve (QNNR Administration, unpublished). Large mammals include snow leopard, wolf, lynx, brown bear (*Ursus arctos*), leopard (*Panthera pardus*), blue sheep (*Pseudois nayaur*), wild ass (*Equus kiang*), Tibetan gazelle (*Procapra ptilicaudata*), and Himalayan tahr (*Hemitragus jemlahicus*).

Some 90,000 people live in the 35 townships of four counties in the reserve: Jilong, Nielamu, Dingri, and Dingjie. Four towns in Dingjie are not within the boundary of QNNR, but we included them in our analysis. Tibetans account for more than 90% of the human population; the rest are Han, Hui and Sherpa ethnic groups. Major livelihoods in the reserve are agriculture and livestock rearing (e.g., yak, cattle, cattle–yak crossbreed, sheep, goat, horse, and donkey).

2.2. Analysis of livestock depredation records

We gathered 9193 livestock depredation records of the compensation scheme from the municipal forestry bureau (2011–2013). We

also collected census data on human population and livestock holding of all townships in 2013 from the county governments. We coded predation incidents by year, month, township, number and type of livestock killed, and predator species. Because the livestock census data that we used did not distinguish livestock species, we followed the common practice of local authorities and classified livestock into large-bodied stock (yak, cattle, cattle–yak crossbreed, horses and donkeys) and small-bodied stock (sheep and goats). According to the compensation scheme, livestock except horses and donkeys are categorized as adult beyond the age of 2, and as juvenile under. The division for horses and donkeys is the age of 3.

First, we described and then analyzed the overall predation rates and compared differences in the total numbers of livestock killed by each predator using repeated measure ANOVA, with month as the repeat variable. Two-way ANOVA test was used to determine if there was a yearly difference in the number of kills by different species. The market value for different types of livestock was estimated by interviewing key informants, and the average value for each type was used to estimate financial losses inflicted by wild carnivores. We converted Chinese Yuan (RMB) to US dollars based on the currency conversion rate at the time of the survey (i.e., US\$ 1 = RMB 6.2).

Second, we adapted an electivity index (E_i^*) which was proposed by Vanderploeg and Scavia, 1979 to analyze livestock preference by different carnivore species in relation to the proportional abundance of large- and small-bodied livestock. Suryawanshi et al. (2013) also used this index to analyze livestock preference of wolves and snow leopards. Electivity index was calculated as: $E_i^* = [W_i - (1/n)] / [W_i + (1/n)]$, where n represents the total livestock types. $W_i = (r_i/p_i) / \sum(r_i/p_i)$, where r_i denotes the proportion of the i th livestock species in the total livestock killed by the carnivore, and p_i denoted the proportion of the i th livestock species in the total population (Suryawanshi et al., 2013).

Third, we analyzed the temporal and spatial patterns of predation events. We analyzed variation in livestock loss in different months using ANOVA Tukey's test. At a township level, we also examined the relationship between the occurrence of predation events (kill/km²/year) and several possibly influential independent variables, including average elevation, average terrain ruggedness, density of large-bodied stock, density of small-bodied stock, human population density, and road density. Remote sensing elevation data of the reserve were obtained from CGIAR Consortium for Spatial Information (Jarvis et al., 2008), and terrain ruggedness was computed using a Vector Ruggedness

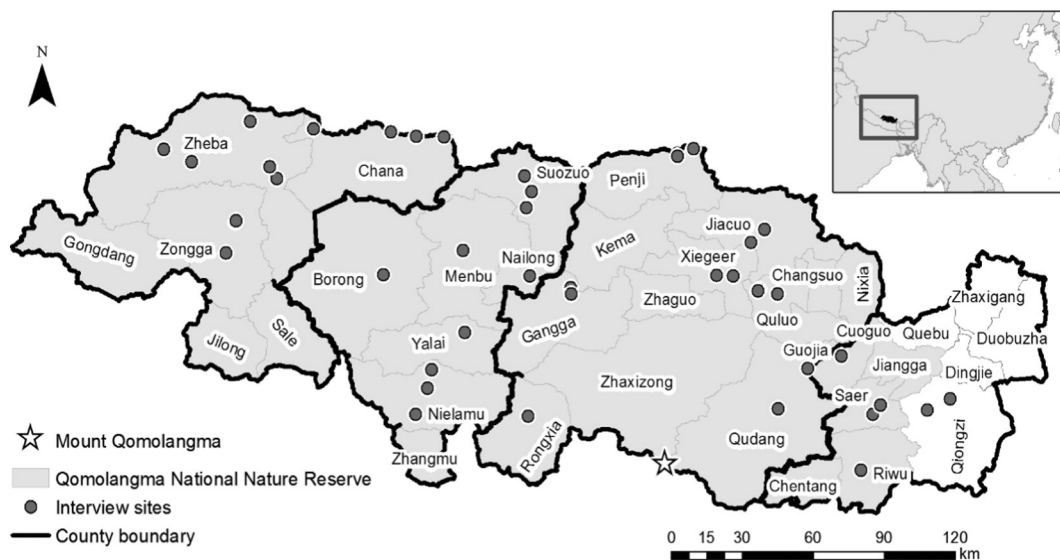


Fig. 1. Map of the Qomolangma National Nature Reserve, which is located in southwestern China along the Himalayas. The reserve is situated within four counties of the Tibetan Autonomous Region, namely (from left to right) Jilong, Nielamu, Dingri, and Dingjie, encompassing 31 towns. Mount Qomolangma (marked as star), the highest mountain on the planet, is located at the southeastern border of the reserve. Locations where we conducted interviews with the locals and government officials during the study were also shown on the map.

Measure tool (Sappington et al., 2007) in ArcGIS. With reference to other studies on similar carnivores and their prey (Ahmadi et al., 2013; Lone et al., 2014; Rauset et al., 2013; Suryawanshi et al., 2013), we set the VRM neighborhood size to three pixels, resulting in a local scale ruggedness index based on nine neighboring cells. Multiple regression analyses (with stepwise backward elimination) were undertaken separately for each of the predators (snow leopard, wolf and lynx), and for all predators combined, using Minitab 17. Explanatory variables that did not meet a threshold of $P < 0.1$ were eliminated until arriving at a final model with a few variables that contributed significantly ($P < 0.05$) to the resultant R^2 value.

2.3. Interview with local villagers and government officials

In May 2015, we conducted structured interviews with local villagers and government officials to understand their perceptions about trends in and causes of livestock predation. We also interviewed them about constraints of the compensation scheme. Our sample was based on analysis of depredation records from which we identified townships with the most serious human–carnivore conflicts. We went to these towns and interviewed township governors or officials responsible for the implementation of the compensation scheme. In each town, township officials helped us to identify 1–3 villages where livestock depredation from snow leopards was frequent. We then visited villages and interviewed the village chief and 2–4 randomly selected local villagers. We coded the responses of our interviewees and conducted a quantitative analysis. All information provided by our respondents was cross-checked using knowledge of QNNR staff who were trained to serve as our Tibetan language interpreters.

3. Results

We describe here the compensation program and the extent of livestock depredation. We also analyze livestock preference of different carnivores and temporal and geographical patterns of livestock depredation. Lastly, we analyze local and official perceptions and evaluated the compensation scheme.

3.1. Structure and workflow of the compensation scheme

A claim for compensation must be reported to the village committee (VC) within 7 days of livestock loss. Fig. 2 shows the workflow of the compensation scheme. The claimant must provide information about the type and number of livestock killed and evidence, such as a carcass photo or video, and witnesses' testimony. The VC then conducts an investigation and submits a compensation application form to the local township government, after the claim is verified. The application form includes personal details of the livestock owner (name, address, and ID), description of the depredation incident (time, location, predator and livestock loss), and the VC's suggestions on how to handle the issue. Once the form is received, the town government evaluates the claim by sending at least 2 officers to the scene of the reported incident. If found to be genuine, the case is accepted, and relevant material is posted publicly in the livestock owner's village for 7 days. If no objection is raised, the town government submits the application form, investigation form, and relevant notes to the county forestry bureau within 15 days. The county forestry bureau examines the submitted materials within 15 days and, if necessary, conducts a third verification. The claim is then forwarded to the county financial department, which is supposed to finish scrutiny within 10 days. If the claim meets the requirements, the county financial department deposits the compensation fund to the town government, which then distributes the money to the livestock owner. The compensation amount is calculated according to a preset standard of values of different livestock types (Table 1). Compensation payments are borne by different levels of the government: TAR covers 60%, municipal government covers 30%, and county-

level government covers 10%. Any individual or group who commits fraud during the process faces punishment or penalty.

3.2. Extent of livestock predation

A total of 26,975 livestock mortalities (9193 incidents) were documented from 2011 through 2013. Of these, 10,157 (37.7%) livestock were killed by wolves, 9326 (34.6%) by lynx, and 5877 (21.8%) by snow leopards. The rest (1615 kills, 6.0%) were attributed to other species such as leopard, brown bear, and Asian black bear (*Ursus thibetanus*). There was no significant difference in the numbers of livestock killed by different species over the three years ($P > 0.05$). Repeated measures ANOVA ($F_{2, 105} = 6.01, P < 0.01$) showed significant difference in the prevalence of livestock depredation by snow leopards, wolves, and lynx. Wolves killed significantly more livestock than snow leopards ($P < 0.05$), and so did lynx ($P < 0.05$). There was no difference in prevalence of livestock predation between wolves and lynx ($P > 0.05$). The number of large-bodied livestock lost per incident ranged from 1 to 19 (snow leopard: 1–19; wolf: 1–13; and lynx: 1–7), while the number of small-bodied livestock loss ranged from 1 to 196 (wolf: 1–196; lynx: 1–99; and snow leopard: 1–47). Sometimes, 10 to 50 or more small-bodied stock were killed in a single incident. Such events (7% of all small-bodied stock depredations) accounted for 34.2% of all small-bodied livestock lost. Similarly, events where more than 5 large-bodied stock animals were killed in a single incident (1.4% of all large-bodied stock depredations) accounted for 10.6% of all large-bodied livestock losses.

In 2013, total livestock loss in QNNR accounted for 1.2% ($n = 10,112$) of the total livestock population ($n = 846,707$): large-bodied stock loss accounted for 1.6% ($n = 1969$) of total large-bodied livestock population ($n = 124,245$), while small-bodied stock loss accounted for 1.1% ($n = 8064$) of total small-bodied livestock population ($n = 722,462$). The compensation payment standards and 2013 market prices of different livestock species are shown in Table 1. The total financial loss arising from livestock depredation in 2013 was estimated at US\$ 2,784,581, while the government was supposed to pay a sum of US\$ 759,245 to offset losses by local residents according to the compensation scheme (actual amount paid was not available to us). The compensation payment was about 27.3% of the market value of livestock loss.

3.3. Livestock preference of different carnivores

Losses of small-bodied livestock, the major predation victims, consisted of 13,786 sheep and 7611 goats, accounting for a combined 79.4% of total livestock loss in 2011–2013. Large-bodied livestock accounted for 20.3% of total livestock loss, including 2795 yak, 935 cattle–yak crossbreeds, 1016 cattle, and others. The rest of the loss involved 72 chickens and 29 pigs. Large-bodied stock killed in 2013 consisted of 217 (10%) juveniles and 1858 (90%) adults, while small-bodied stock loss in the same year included 338 (4%) juveniles and 8106 (96%) adults.

In 2013, electivity index of wolves was positive for small-bodied stock ($n = 2922, E^* = 0.17$) and negative for large-bodied livestock ($n = 545, E^* = -0.25$). Likewise, lynx showed a positive index for small-bodied livestock ($n = 3685, E^* = 0.22$) and a negative index for large-bodied stock ($n = 450, E^* = -0.39$). In comparison, electivity index of snow leopards for large-bodied stock was positive ($n = 838, E^* = 0.10$), but negative for small-bodied stock ($n = 1262, E^* = -0.12$). In summary, these data indicated that wolves and lynx tended to take small-bodied stock, whereas snow leopards showed a preference for large-bodied livestock even though, in terms of quantity, snow leopards killed more small-bodied than large-bodied stock.

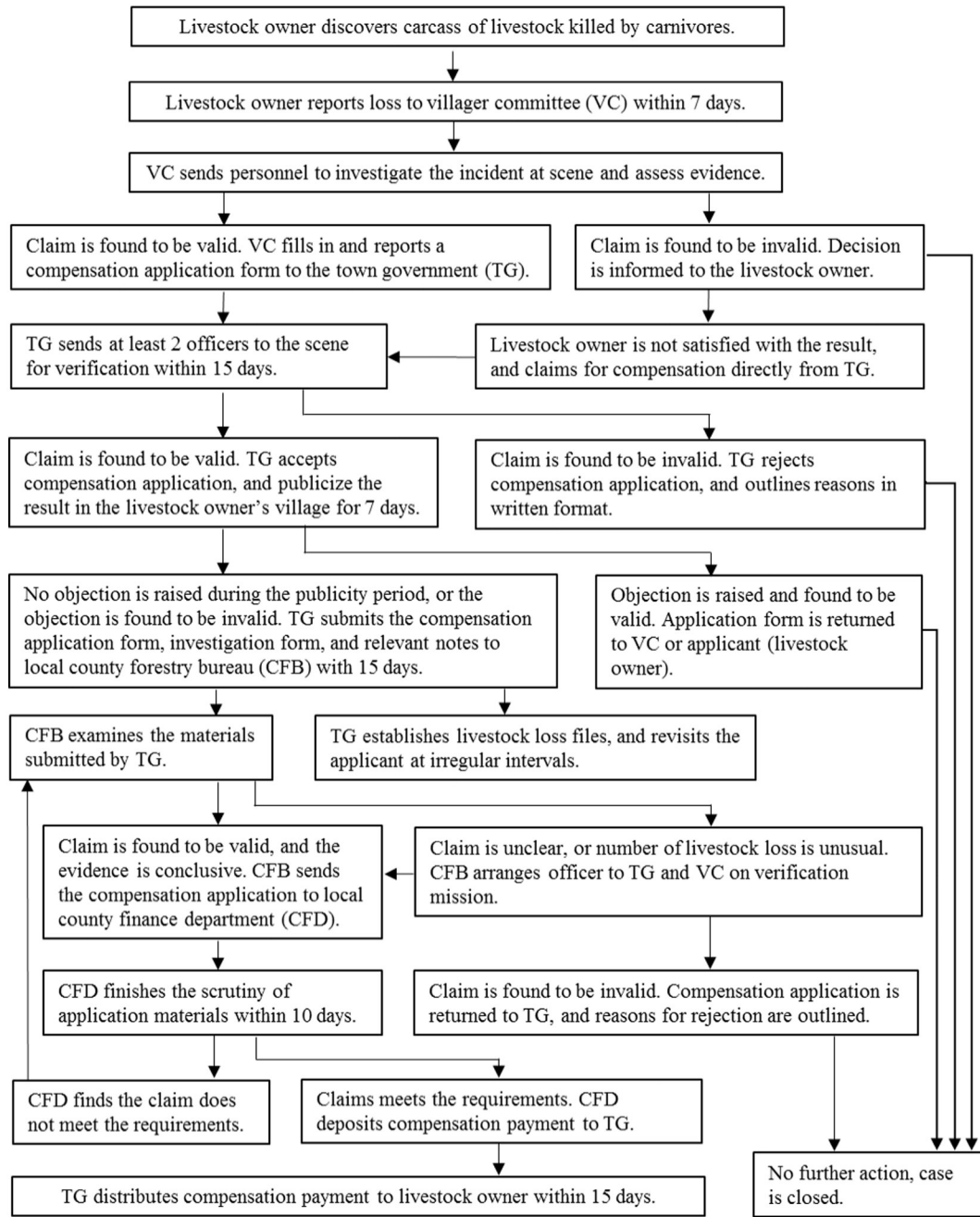


Fig. 2. A flow diagram showing the workflow of the compensation scheme adopted by the TAR authorities.

3.4. Monthly differences in predation intensity

Fig. 3 shows the average number of large- and small-bodied livestock killed in each month by snow leopards, lynx, wolves, and all predators combined. ANOVA Tukey's test detected monthly variability of

livestock loss (Table A1 in Appendix). Wolves killed more small-bodied livestock ($F = 2.37, P < 0.05$) in June (373 ± 258) and July (374 ± 247), and more large-bodied livestock ($F = 2.94, P < 0.05$) in July (61 ± 28). But in December fewer livestock, either large- (4 ± 7) or small-bodied (14 ± 20), were killed by wolves compared to the other months. Frequency of kills by lynx, both small-bodied livestock ($F = 3.13, P < 0.01$) and large-bodied livestock ($F = 1.35, P > 0.05$), was consistent throughout the year with no monthly difference detected. As for snow leopards, predation of small-bodied livestock ($F = 1.94, P > 0.05$) showed no difference throughout the year, but marginally more large-bodied livestock ($F = 2.20, P > 0.05$) were killed in January (128 ± 74) and fewer in November (21 ± 11). All predators combined, depredation of small-bodied livestock ($F = 7.56, P < 0.01$) was most severe in July (852 ± 146) and least serious in December (106 ± 119), while depredation of large-bodied livestock ($F = 3.99, P < 0.01$) was most severe in January (195 ± 84) and least serious in November

Table 1

The market prices (US\$) and compensation payment standards (US\$) of different livestock species in 2013 (market price/compensation standard). According to the compensation scheme, livestock except horses are categorized as adult beyond the age of 2, and as juveniles under. The division for horses is set at the age of 3.

	Yak and cattle-yak crossbred	Cattle	Farm cattle	Sheep	Goat	Horse
Adult	1371/242	565/156	806/323	73/40	81/32	565/419
Juvenile	565/24	161/16	-	32/8	32/6	129/81

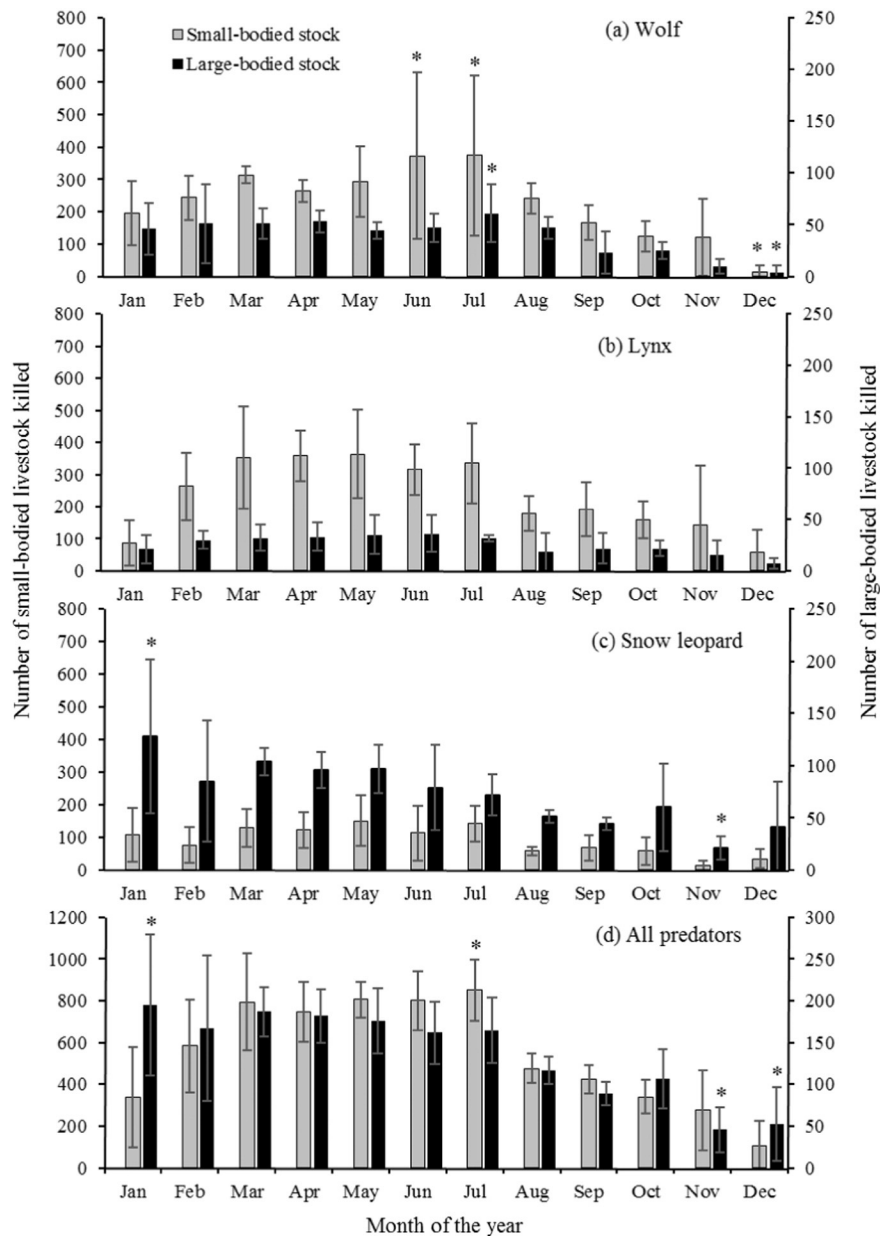


Fig. 3. Number of livestock killed in each month of the year by (a) wolves, (b) lynx, (c) snow leopards, and (d) all carnivores from 2011 to 2013 on average. Months with number of kills significantly different from other months were marked with asterisks. Details of the ANOVA Tukey's test can be found in Table A1 of Appendix.

(46 ± 27). Overall, about 59% of losses occurred from March to July, whereas less than 25% of kills took place during September to January.

3.5. Spatial pattern of depredation

Of the 36 towns in the study area, we included predation records and corresponding data from 34 towns to identify the spatial patterns. Data from two towns (Zhangmu and Sale) were excluded because the compensation scheme was not introduced/promoted to the areas and subsequently a lack of depredation reports existed. Whereas depredation occurred across all towns with an average of 1.2% livestock lost, their abundance was most severely impacted in Rongxia (5.1%) and Nielamu (2.4%) in the southern part of QNNR, and Chentang (3.6%) at the eastern border of the reserve. In terms of depredation prevalence, 8.3% of all livestock kills occurred in Zheba, followed by 6.3% in Duobuzha, while the remaining kills were distributed fairly evenly across other towns (Fig. 4). Predation prevalence by each kind of predator revealed divided spatial distribution. Snow leopard depredations were reported in 23 of

the towns. Forty-one percent of the kills were reported from three towns in the southern part of QNNR. Twenty-eight towns reported depredation by lynx, covering most of the reserve with similar percentages of kills. Wolf depredation was most severe in Zheba in western QNNR, with 20.4% of all livestock lost to wolves occurring in the town.

Multiple regression analysis was undertaken to investigate the relationship among these factors, and the Akaike Information Criterion (AIC) used for model selection (see Table A2 in Appendix for detailed statistical analysis results). The best model that described the greatest variance in overall depredation ($R^2 = 0.742$) included a positive relationship with terrain ruggedness ($P < 0.05$) and small-bodied livestock density ($P < 0.01$), and a negative relationship with large-bodied livestock density ($P < 0.01$). The best models for both lynx ($R^2 = 0.469$) and wolf depredations ($R^2 = 0.282$) only included a positive relationship with small-bodied livestock density ($P < 0.01$), while that for snow leopard depredation ($R^2 = 0.156$) included a significant positive relationship with terrain ruggedness ($P < 0.05$).

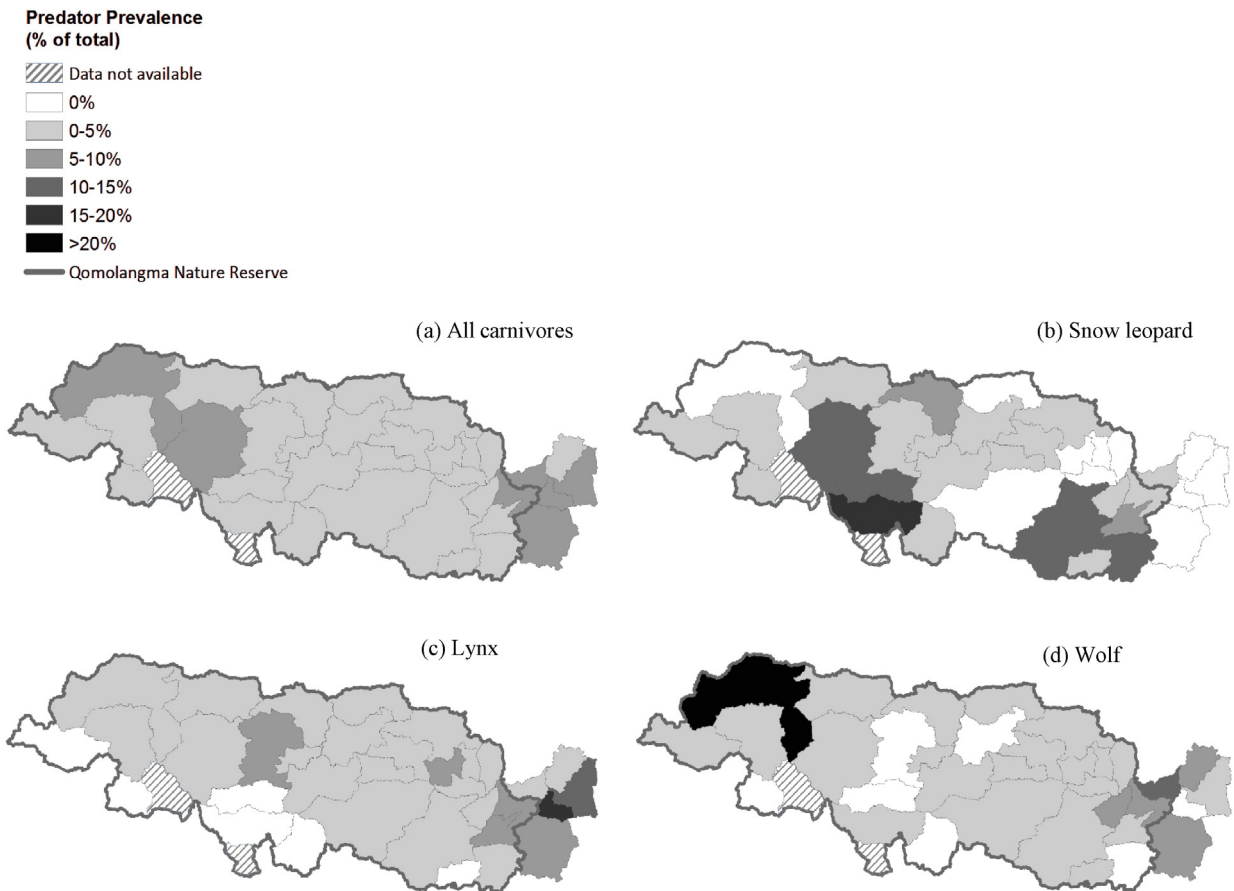


Fig. 4. Livestock predation prevalence pattern in QNNR, showing kills per town as a percentage of total livestock lost in the whole area, by (a) all carnivores, (b) snow leopards, (c) lynx, and (d) wolves.

3.6. Local perceptions toward human–carnivore conflict and the compensation scheme

We interviewed 116 people from 33 villages of 20 towns. Most (n = 101, 87%) of the respondents were male. Ninety-four (81%) were local villagers, and the rest (n = 22, 19%) were government officials. Among the local villagers, two people did not own any livestock, 53 villagers reported their livestock populations had decreased over 2012–2014, while the livestock of 22 villagers remained unchanged. Eighty-two villagers reported losing some livestock to predators over the previous three years. When asked about main problematic predators that affected them, 86% of our respondents mentioned wolves, 67% mentioned snow leopards, and 48% mentioned lynx. Other species cited included feral dogs, raptors, foxes and brown bears. The majority (68%) of respondents believed that the overall livestock depredation rate had increased. Among these respondents, most (74%) attributed the increase to carnivore population growth, whereas 7% cited lax livestock grazing practices and 5% mentioned livestock population increase. Eleven percent of the interviewees said they had no idea, and the rest (5%) mentioned other reasons, for example, that carnivores were not able to find sufficient food in the wild, or that carnivores had become habituated to preying on livestock.

Twenty-one officials (95.5%) and 67 local villagers (71.3%) held that the existing compensation scheme is plagued by problems. Among them, 52% (n = 11) of the officials and 51% (n = 34) of the locals attributed the problem to the collecting and verifying of evidence (Fig. 5). They complained about the remoteness and inaccessibility of predation sites. Also, livestock owners sometimes could not obtain predation evidence because the remains were totally eaten by predators; these cases were not eligible for compensation. Moreover, it was difficult to

distinguish damage by different wildlife (e.g., between feral dogs and wolves). False claims (i.e., intentional attribution of livestock deaths to wild predators) were rarely mentioned by officials or villagers. Twenty-four percent (n = 5) of the officials and 21% (n = 14) of the locals thought that the compensation procedure was complicated and unclear. They complained about the application and verification processes, which were both time consuming and demanding in terms of effort. A related problem was the delay in making compensation payments, which can take up to two years, as was pointed out by 29% (n = 6) of the officials and 12% (n = 8) of the locals. During this period, those in charge of the compensation program may have shifted to other

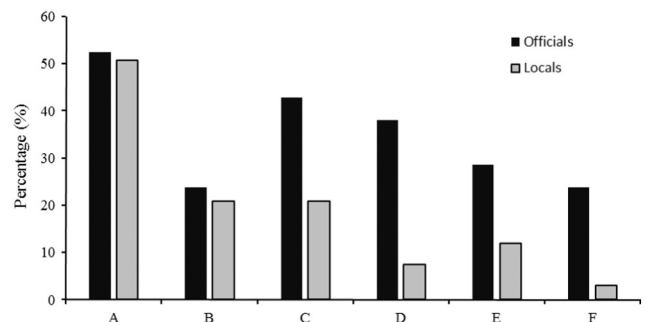


Fig. 5. The views of government officials (n = 21) and local residents (n = 67) on the problems of the compensation scheme, shown in percentage. We coded interviewees' responses into five categories: A. "Difficulty in collecting and verifying predation evidence"; B. "Complicated and unclear application procedure"; C. "Low compensation standard"; D. "Lack of operational resource"; E. "Delay in making payment"; F. "Others".

positions or departments, resulting in the loss of depredation records and relevant files. Untimely payment also caused confusion and frustration among local residents who cannot properly check if they received the payment. In addition, 43% ($n = 9$) of the officials and 21% ($n = 14$) of the locals pointed out that the payment standard was much lower than the market value. Furthermore, 38% ($n = 8$) of the officials complained that there were insufficient resources, such as operational budget, equipment, and personnel. Seven percent ($n = 5$) of the locals commented on the lack of ancillary equipment to collect necessary evidence, e.g., cameras.

4. Discussion

Here we discuss the extent of human–carnivore conflicts in QNNR and explain the temporal and spatial patterns. We also examine local perception and evaluate the implementation of the compensation scheme, based on which we propose strategic recommendations to expedite problem solving and facilitate human–carnivore coexistence.

4.1. Human–carnivore conflicts in QNNR

Our study represents the first systematic investigation of the issue in the northern slopes of the Great Himalayan Region, over two decades after Jackson et al. (1994) conducted a preliminary survey of livestock predation by snow leopards in the area. Our study depended largely on livestock depredation records that were collected for compensation purposes. Although strict measures have been taken to verify the credibility of the records, our results have to be interpreted with caution. During our interviews, some officials pointed out that the extent of livestock depredation was possibly overestimated because locals can fabricate damage evidence to get compensation. On the other hand, some local residents complained that qualified depredation evidence was hard to obtain and sometimes evidence got lost, resulting in underestimation of depredation levels. Nevertheless, generally officials and locals thought that the conflict reports indicated the actual situation, after we showed them our preliminary results.

As is evident from our data, wolves, lynx, and snow leopards are the major predators that cause conflicts with local residents. Other species, such as brown bears and leopards, despite their existence in the area, generally do not present a serious problem, although they might do so in some specific locations. Feral dogs were also mentioned by some interviewees, but livestock loss by dogs is not eligible for compensation. At times, feral dogs also attacked the blue sheep and even snow leopards, as far as we were told by locals. Feral dogs in some places on the Tibetan Plateau have become a menace (G. Schaller, personal communication, 19 August 2015), and this issue requires more attention. Jackson et al. (1994) estimated that in QNNR, the rate of livestock loss by wild predators varied between 1 and 3% on average annually. This is comparable to our results, which revealed that reported livestock loss constituted only 1.2% of the total stockholding in 2013. We found great variability across regions, with depredation rates in some “hotspots,” such as Rongxia, as high as 5.1%. The rate of livestock killed by snow leopards is only 0.19% and that appears to be much lower than the average of 1 to 3% in other snow leopard ranges (Jackson, 2015). We also found that wolves and lynx killed more livestock than snow leopards, but the difference is not as significant as reported in other areas (Alexander et al., 2015; Li et al., 2013).

Our results revealed notable differences in livestock selectivity by wolves, lynx, and snow leopards. Snow leopard predation on large-bodied stock is disproportionately high, whereas wolves and lynx tend to take sheep and goats. This difference in livestock selection was also reported in other areas, such as Bhutan (Sangay and Vernes, 2008) and India (Suryawanshi et al., 2013). Because large-bodied stock have a much higher economic value compared with sheep and goats, it is expected that the killing of a yak prompts immediate and far greater hostility from the local community, even though in terms of numbers, snow

leopards kill fewer livestock than either wolves or lynx. Another phenomenon that is worth attention is “surplus killing” (Jackson, 2015), which occurs when predators enter a night-time corral and kill 10 to 50 or more livestock in a single event. One case we learned about involved four wolves that killed more than 200 sheep in a single night in 2014. Such scenarios trigger anger from local communities and have a high probability of leading to retributive killings (Jackson, 2015).

Diverse and complex factors contribute to the temporal and spatial variations in the distribution of livestock depredation. These include livestock species composition, wild prey availability, livestock herding and guarding practices, local abundance of predators, predator behaviors, habitat characteristics of rangelands, and others (Dar et al., 2009; Jackson, 2015; Sangay and Vernes, 2008; Suryawanshi et al., 2013; Thorn et al., 2012). Our analysis of monthly differences in predation intensity showed that the period from March to July is the most prone to livestock depredation. This period corresponds with the most active time (from mating to reproducing) of the three major predators: wolf (February–June), lynx (January–June) and snow leopard (January–June) (IUCN, 2015). It is also a period when local residents are busy with lambing (February), sowing (April–May), sheep shearing (June) and collecting *Cordyceps sinensis* caterpillar fungus (May–June). Livestock management tends to be lax during this season. In addition, livestock are in their weakest condition during March and April as a consequence of poor nutritional status and severe weather events. It is also noted that depredation patterns differ between small-bodied and large-bodied livestock and between different predators. Depredations of sheep and goats by wolves are the most severe in June and July, while snow leopard predation on yaks is most prevalent in January. This is likely the result of different herding and management practices for large-bodied and small-bodied stock. Another likely explanation for the different predation patterns that we documented is that seasonal livestock migrations, in association with predatory strategies of different predators, alter the prey availability in predator-rich areas. However, further research is needed before we can finalize this explanation.

4.2. People's perceptions about the trends in and causes of conflicts

Most our interviewees believed that livestock depredation by wild carnivores was on the rise. Whereas researchers (i.e., Dar et al. (2009) and Jackson et al. (1994)) tend to blame depletion of wild prey and lax animal husbandry practices, local residents in QNNR generally attributed the problem to carnivore population growth, notably wolf recovery. The wolf is the species that causes most conflicts with local residents, according to both reported depredation incidents and people's perceptions. Interviewees responded that the wolf population had increased dramatically owing to government's conservation policy and the species' high reproductive capacity. In the past, local people persecuted wolves by removing cubs from maternal dens, but nowadays this practice is forbidden. Interviewees reported that wolf encounters near village were more frequent, and some people reported seeing wolf packs of up to 12 individuals. In addition to the perceived threat that wolves may present to livestock, local residents also voiced concerns about threats to personal safety. Many villages requested county forestry bureaus to allow wolf hunting. However, little evidence shows that there is any retaliatory poaching of wolves in recent years (Chen et al., unpublished results). It is plausible that the creation of QNNR and enforcement of wildlife protection laws have permitted recovery of carnivore populations, although there is little scientific evidence to support this perception. It is likely that local people, out of a negative attitude toward “problem animals,” have a propensity to exaggerate numbers of wild carnivores. Moreover, the perceived increase in livestock depredation may be a result of more reporting in order to get compensation, though the extent of this is difficult to gauge.

4.3. Evaluation of the compensation scheme

A variety of responses have been proposed to address human–carnivore conflicts (Clark and Rutherford, 2014; Goodrich, 2010; Inskip and Zimmermann, 2008; Jackson, 2015; Pettigrew et al., 2012). Among them is financial compensation for livestock loss (Dickman et al., 2011; MacLennan et al., 2009; Nyhus et al., 2003; Jackson et al., 2010). Whereas reimbursing local residents for economic loss incurred as a consequence of livestock depredation has the potential to increase tolerance and foster more positive attitudes toward large carnivore conservation, some studies revealed that such programs often fall short of their conservation objectives (Pettigrew et al., 2012; Rosen et al., 2012). In reality, such programs are often plagued by many difficulties linked to damage verification, program guidelines, payment process, funding and other factors (Nyhus et al., 2003, 2005). Our study identified similar problems that exist in the current compensation scheme adopted by the TAR authorities.

Generally, wildlife-related policy in China is carefully designed with many stringent requirements, but it is often not being effectively implemented. Widely accepted standards of implementation in the management decision process include timeliness, rationality, nonprovocateness, and uniformity (Brunner et al., 2005; Clark and Rutherford, 2014; Lasswell and Kaplan, 1950). Clearly, compensation implementation in QNNR only partially meets these ideal standards. Research has identified variables that confound policy implementation (Sabatier, 1986; Van Meter and Van Horn, 1975). As compensation implementation in QNNR includes different levels and agents of government, it inevitably involves many bureaucratic elements, and the outcomes ultimately depend on the interaction among implementing authorities and other stakeholders, such as locals who experience conflicts.

Finally, implementation is but one of the interactive functions or activities comprising any complete decision process (Clark, 2002). Other functions include defining a problem through collecting and analyzing information, debate over a true estimation of the problem at hand and what to do about it, selecting a goal and course of action, appraising or monitoring and evaluation of progress, and finally adjusting the whole process or parts to make the selected policy more effective, efficient, and equitable or moving on and trying again. The content, process, and quality of these interrelated functions determine whether sound decisions are even possible, whether they are actually taken and implemented, and whether they are effective.

4.4. Recommendations

It is difficult to project the future extent of human–carnivore conflicts in QNNR. On one hand, livestock populations are decreasing largely because of the government's grazing restriction policy for rangeland protection. At the same time, local residents now have more alternative income sources than ever before, such as collecting caterpillar fungus and working as migrant workers. Hence, their dependence on livestock rearing will probably decline. On the other hand, market value of livestock is increasing rapidly, and consequently, financial loss from livestock depredation is on the rise. Carnivore population recovery, as a result of effective conservation measures, along with anticipated increases in human activities in the reserve, may also exacerbate the conflicts.

In the face of this uncertain future, we offer strategic recommendations to help foster human–carnivore coexistence. First, we recommend focusing on problems to find solutions (see Clark (2002)). As Jackson (2015) aptly pointed out, compensation “addresses the symptoms rather than the underlying root cause for depredation loss.” It is recommended that mechanisms of reward or punishment should be incorporated with the existing compensation program by linking it with promoting the best and highest standards of livestock husbandry practices (Jackson, 2015). Since human–carnivore interactions show

great variability across space and time, locally crafted approaches are needed to address the context-specific conditions and drivers that cause the conflicts. Second, we recommend examining the complexity inherent in human–carnivore interactions by mapping the ongoing social process/context. This involves different participants with diverse perspectives interacting with each other using various resources and strategies (Clark, 2002; Clark and Rutherford, 2014). Third, any possible policy solutions should make efforts to establish an adequate decision-making management process, from initial problem analysis and definition, public involvement and mobilization, setting rules and regulations, resource allocation, and implementation, to monitoring and evaluation, and eventually policy succession. In the end, we believe that human–carnivore coexistence in QNNR and elsewhere would benefit greatly from a problem-oriented, integrated, adaptive approach that targets the complex social process at the heart of the conflict and addresses the interrelated functions of the decision process.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.biocon.2016.02.026>.

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