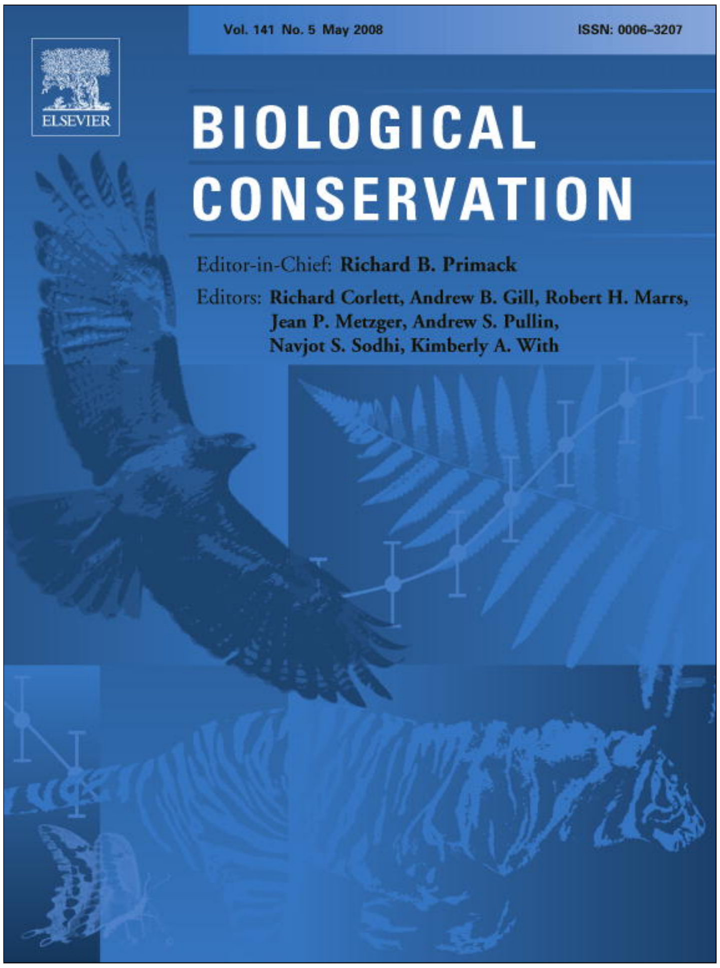
Vol. 141 No. 5 May 2008
ISSN: 0006-3207
ELSEVIER
BIOLOGICAL CONSERVATION
Editor-in-Chief: Richard B. Primack
Editors: Richard Corlett, Andrew B. Gill, Robert H. Marrs,
Jean P. Metzger, Andrew S. Pullin,
Navjot S. Sodhi, Kimberly A. With

BIOLOGICAL CONSERVATION 141 (2008) 1272–1282

available at www.sciencedirect.com

ScienceDirect

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

Human–wildlife conflict in the Kingdom of Bhutan: Patterns of livestock predation by large mammalian carnivores

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ARTICLE INFO

Article history:
Received 21 May 2007
Received in revised form
23 February 2008
Accepted 25 February 2008
Available online 8 April 2008

Keywords:
Depredation
Tiger
Leopard
Bear
Himalayas
Compensation
Hotspot

ABSTRACT

We examined predation activity throughout Bhutan by tiger (*Panthera tigris*), common leopard (*Panthera pardus*), snow leopard (*Uncia uncia*) and Himalayan black bear (*Ursus thibetanus*) on a variety of livestock types using data gathered over the first two years (2003–2005) of a compensation scheme for livestock losses. One thousand three hundred and seventy five kills were documented, with leopards killing significantly more livestock (70% of all kills), than tigers (19%), bears (8%) and snow leopards (2%). About 50% of livestock killing were of cattle, and about 33% were of horses, with tigers, leopards and snow leopards killing a significantly greater proportion of horses than predicted from availability. Examination of cattle kills showed that leopards killed a significantly greater proportion of smaller prey (e.g., calves), whereas tigers killed a significantly greater proportion of larger prey (e.g., bulls). Overall, livestock predation was greatest in summer and autumn which corresponded with a peak in cropping agriculture; livestock are turned out to pasture and forest during the cropping season, and subsequently, are less well guarded than at other times. Across Bhutan, high horse density and low cattle and yak density were associated with high rates of livestock attack, but no relationship was found with forest cover or human population density. Several northern districts were identified as 'predation hotspots', where proportions of livestock lost to predation were considerable, and the ratio of reported kills to relative abundance of livestock was high. Implications of our findings for mitigating livestock losses and for conserving large carnivores in Bhutan are discussed.

1. Introduction

The Kingdom of Bhutan is a landlocked country in the eastern Himalayas bordered by China to the north, and India to the east, south and west. With a total land area of just over 38,000 km^2 (NCD, 2004), Bhutan has an extraordinarily rich biological diversity, and the entire country is included within one of the world's global biodiversity hotspots (Myers et al., 2000). Bhutan draws its mammals from two faunal regions, the Palaearctic region of the temperate and alpine areas of the central and northern mountains, and the Indo-Malayan region of the tropical and sub-tropical forest ecosystems of the lowlands and southern foothills. Large carnivorous mammals of the palaearctic include snow leopard (*Uncia uncia*) and Himalayan black bear (*Ursus thibetanus*), while Indo-Malayan carnivores include tiger (*Panthera tigris*), common leopard (*Panthera pardus*), and clouded leopard (*Neofelis nebulosa*).

Agriculture and animal husbandry is the mainstay of the Bhutanese economy, providing occupation and livelihood to 79% of the population and contributing substantially (33%) to the country's gross domestic product (RGoB, 2005a). As such, livestock are important to Bhutanese farming families

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doi:10.1016/j.biocon.2008.02.027

and contribute importantly to the rural economy, providing dependable food and revenue. Practically every Bhutanese family living in a rural area owns a small parcel of land to farm subsistence food crops and to keep a variety of domestic animals, principally cattle, horses, yaks, sheep, goats and buffalo. Bhutanese farmers also depend on nearby forested areas for non-wood forest products and fuel wood for energy, and almost all livestock are grazed, at least for part of the year, untended in pasture or open forest.

One of the main contributors to human–wildlife conflict in Bhutan is predation of livestock by wild mammalian carnivores (NCD, 2004; Wang and Macdonald, 2006; Wang et al., 2006). In Bhutan, tiger, snow leopard, leopard, bear, wild dogs (*Cuon alpinus*) and smaller cats (*Felis chaus*, *F. bengalensis*, *F. manul*, *Pardofelis marmorata*, *Catopuma temmincki*, *Prionailurus bengalensis*) kill various livestock ranging in size from poultry to large bovids, and have less frequently been responsible for injury to humans (Sangey, 2000; NCD, 2001a,b; NCD, 2003; NCD, 2004). Predation of livestock by carnivores is related in part to the type of livestock kept, as well as stock management practices. Wang and Macdonald (2006) cite lax herding, inadequate guarding of stock, and overgrazing as contributing factors to livestock loss. However, a host of other factors outside of the control of individual farmers such as predator density, individual predator behavior, prior experiences of the predator, natural prey population and predator-prey interactions are clearly also important (Mishra et al., 2001).

In recent history, human–wildlife conflicts have generally increased across Bhutan (NCD, 2004; Wang and Macdonald, 2006). This may be linked to recent increases in income level and living standards that have allowed some farmers to keep more livestock (Govil, 1999), increasing the likelihood that predators will kill livestock and come into conflict with humans (Seeland, 2000). Abundance of domestic stock has shown to be correlated to 'predation hotspots' in Bhutan (Wang and Macdonald, 2006) and elsewhere (Yom-Tov et al., 1995; Stahl et al., 2001; Bagchi and Mishra, 2006; Michalski et al., 2006). Wang and Macdonald (2006) and Wang et al. (2006) also noted that new conservation legislation enacted in the mid-1990s (Forest and Nature Conservation Act of Bhutan, 1995) placed new restrictions on the use of common grazing lands by farmers, and this may have intensified human–wildlife conflict in some places. Furthermore, a central tenet of the Act is the conservation of protected wildlife (including tigers, leopards, snow leopards and bears), however, farmers in central Bhutan rank livestock predation as one of the most serious threats to their livelihood, and many farmers express a desire to eradicate problem wildlife (Wang et al., 2006). If conservation legislation is to be truly successful in conserving Bhutan's large predatory mammals, human–wildlife conflicts must be minimized wherever possible. In other parts of the Himalayas, high populations of domestic livestock have led to increased predation of domestic species by wild carnivores (Mishra, 1997; Namgail et al., 2007), and in most instances, a heavy financial burden is paid by pastoralists (Mishra, 1997; Maikhuri et al., 2000; Wang and Macdonald, 2006; Namgail et al., 2007).

Conflict between humans, and carnivores that kill livestock is a worldwide phenomenon with significant conservation implications. Well known examples of human–carnivore conflict include hyenas (*Crocuta crocuta*) and lions (*P. leo*) in Africa (Patterson et al., 2004; Kolowski and Holekamp, 2006); snow leopards (*U. uncia*) in India and Pakistan (Hussain, 2003; Jackson and Wangchuk, 2004; Bagchi and Mishra, 2006) wolves (*Canis lupus*) in North America (Musiani et al., 2003), puma (*Puma concolor*) and jaguar (*Panthera onca*) in South America (Mazzolli et al., 2002; Polisar et al., 2003) and dingoes (*Canis lupus dingo*) in Australia (Allen and Sparkes, 2001). Compared with many regions, however, livestock predation by carnivores in Bhutan has not been adequately assessed, with only one study (Wang and Macdonald, 2006) in a single National Park in central Bhutan having been undertaken.

In this paper we report on the first two years (October 2003–December 2005) of data from 'The Tiger Conservation Fund' (TCF), a scheme established by the Government of Bhutan to compensate farmers for livestock losses to large predators (Sangay, 2006). Because of the rigor involved in verifying predation of livestock before compensation is paid under this scheme, we were able to reliably use data gathered by the TCF to examine seasonal patterns of predation by different predators for different age and sex classes of livestock types across the 20 districts (dzongkhags) that together comprise the Kingdom of Bhutan. Based on these analyses, we offer recommendations on how future livestock losses, and thus human–wildlife conflicts, can be minimized in Bhutan.

2. Methods

2.1. Protocol for the assessment of claims

A major management challenge to the tiger conservation fund was to only pay compensation where genuine cases of livestock predation by the wild carnivores covered under the scheme had occurred. In this pursuit, a rigorous verification mechanism was established in order to minimize false claims. The TCF required those making a claim to seek three types of evidence before a claim could be processed. First, the community leader (Gup) or community representative to the National Assembly (Chimi) must support the veracity of the claim. This first step also required that information about livestock holding facilities and the stock rearing systems were collected. Second, a veterinarian confirmed, by post mortem examination of the carcass, that a predator killed the animal, rather than scavenging it after death. Third, a local forest or park staff member confirmed the range of the predator claimed to have made the kill, and cross checked the information against the known presence of the predator locally through various types of indirect evidence such as scat, tracks, and other signs. Once these three forms of documentary evidence were completed, the claim was forwarded to the Divisional Forest Officer or Park Manager who further evaluated the claim based upon the evidence presented. If at that point the case was supported as valid, it was forwarded to the tiger conservation fund for compensation payment.

Before the scheme was put into effect, management conducted regional training sessions for community leaders, foresters and veterinarians. Training focused on understanding different predatory behaviors, how to recognize feeding signs of predations, indirect evidences such as tracks and faeces, and correct ways to complete forms. Training was conducted with an aim to standardize the use of forms that would ultimately ease future analysis of data. Simultaneously, the compensation scheme was broadcasted through the national radio channel in four major languages (Dzongkha, Sharchop, Nepali and English) as part of a coordinated campaign to inform the wider community of the compensation scheme.

2.2. Data analyses

For our analyses, we coded predation events that had been documented by the TCF by dzongkhag (district), month and type of predator. We classified predated livestock into types based upon species of livestock, and where appropriate, sex and/or age class of the livestock. Accordingly, cattle were classed as bull, cow or calf; and 'horses' (encompassing horses, donkeys, and mules) were classed as adult or foal. Young age classes (foal or calf) were those sub-adult individuals estimated to be less than three years of age at the time they were killed. Sheep were not classified by sex or age, because the predators we studied would be unlikely to distinguish between sheep on the basis of size or sex, while for yaks, separate analyses of age and sex were not warranted, because there were too few predation events.

Differences in the total numbers of livestock killed by each predator in 2004 and 2005 were analysed using repeated measures ANOVA, with month as the repeat variable. Relationships between predator type and the livestock type they killed were examined using Chi-square goodness of fit tests, and a Chi-square test of independence was used to determine whether there were seasonal (month by month) changes in the frequency of predation by each predator for each livestock type. For these Chi-square tests, we calculated an expected rate of predation on livestock type by the various predators based upon livestock census data for the kingdom of Bhutan (RGoB, 2000). Because the livestock census data we used did not partition livestock type into age and/or sex classes, we performed additional analyses of livestock predation by the two main predators, tigers and leopards, separately for cattle (partitioned into calf, cow and bull classes), and horses (partitioned into adult and foal classes) using Chi-square tests of independence. These latter tests assumed that tigers and leopards each had equal access to the different age/sex classes within each livestock type, and thus sought to determine whether there was preference for livestock class within each livestock type.

At a coarse landscape level, we examined the relationship between the occurrence of predation events per unit of land area and the density of cattle, yak, horses and sheep (livestock/km^2; from RGoB, 2000), human population density (people/km^2; from RGoB, 2005 b) and percentage forest cover for open and closed forest types (from RGoB, 2000) for each of the 20 dzongkhags that comprise the Kingdom of Bhutan. General trends were first examined with simple linear correlations, then more complex interactions were explored between variables using multiple regression. Multiple regression analyses (with stepwise backward elimination) were undertaken separately for each of the predators (tiger, leopard, snow leopard and bear), and for all predators combined. Forest cover, prey density (cattle, yak, horse and sheep), human population density, and the density of other predation events (kills/km^2/year) were initially entered into each model as explanatory variables, followed by stepwise elimination of variables that did not meet a threshold of $P < 0.1$ until we arrived at a final model with a few explanatory variables that contributed significantly ($P < 0.05$) to the resultant R^2 value. Rejection of all variables meant that we could not explain the pattern of predation observed. We also assessed each dzongkhag on the ratio of reported kills to livestock abundance, to determine whether we could identify any 'predation hotspots'.

3. Results

3.1. Predation rates

During these two years, 1375 livestock kills were reported and verified as having been made by tigers, leopards, snow leopards or Himalayan black bears. Of these, 966 (70%) livestock were killed by leopards, 263 (19%) by tigers, 114 (8%) by bears, and 32 (2%) by snow leopards. There were significant differences in the proportion killed by each predator ($F_{3,95} = 75.5$; $P < 0.0001$), which was largely driven by leopards killing significantly more prey than each of the other predators ($P < 0.001$; Tukey–Kramer multiple comparisons). Tigers also killed more livestock than snow leopards ($P < 0.01$). There were no differences in the prevalence of livestock predation between tigers and bears, and snow leopards and bears.

3.2. Livestock type killed

From 2003 to 2005, half of all livestock killed were cattle (430 cows, 209 bulls and 125 calves for a combined total of 50%), and about a third were horses (477 horses and 37 foals for a combined total of 33%). All predators killed at least some livestock types in proportions that were significantly different to the expected frequencies calculated from livestock census data. Tigers killed cattle and yak according to their availability, but more horses and fewer sheep than expected ($X^2 = 33.4$, $P < 0.0001$; Fig. 1). Leopards killed fewer cattle and yak than expected, and more horses and sheep than expected ($X^2 = 238.1$, $P < 0.0001$; Fig. 1). Snow leopards killed fewer cattle and sheep than expected, and more horses and yak than expected ($X^2 = 614.4$, $P < 0.0001$; Fig. 1). Bears killed fewer cattle than expected, and more sheep and yak than expected ($X^2 = 230.2$, $P < 0.0001$; Fig. 1). In summary, these data suggest that horses are killed by tigers, leopards and snow leopards in numbers that are disproportionate to their availability. Similarly, more sheep are killed by bears, and more yaks are killed by snow leopards and bears than availability of these prey would suggest.

Detailed examination of cattle predation revealed that tigers and leopards varied significantly in the livestock classes they killed ($X^2 = 33.4$, $P < 0.0001$), with tigers primarily killing cows and bulls, and very few calves; while leopards killed many calves and cows, and relatively few bulls (Fig. 2). There was, however, no significant difference between tigers and leopards in the predation of foals and horses ($X^2 = 0.37$, $P = 0.54$).

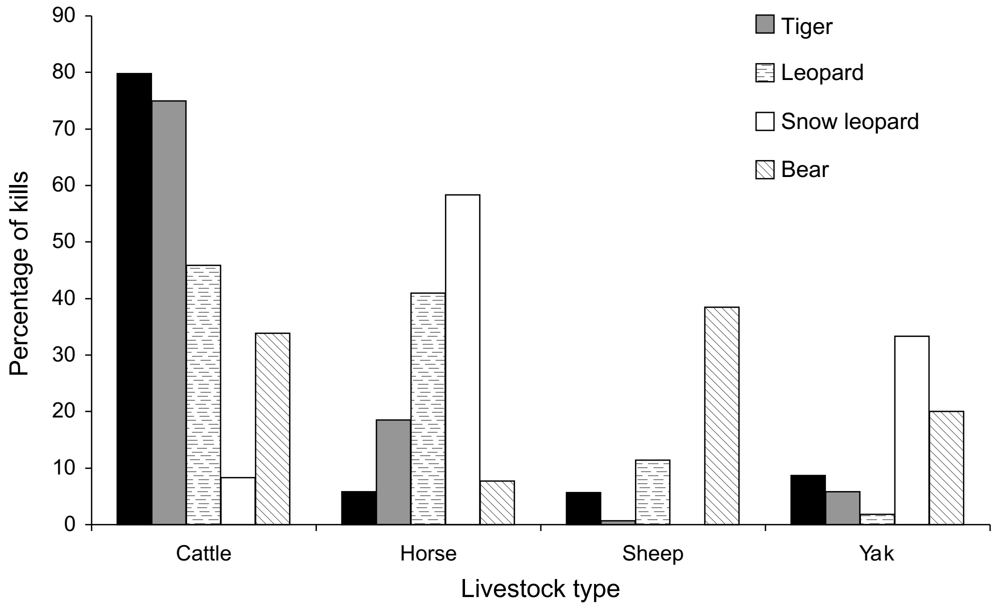

Fig. 1 – The percentage of different livestock types that made up the total kills by tigers, leopards, snow leopards and Himalayan black bears in 2004 and 2005 according to reports verified under the tiger compensation fund. The black bar for each livestock type indicates the expected percentage contribution to all kills, based upon livestock census data (RGoB, 2000).

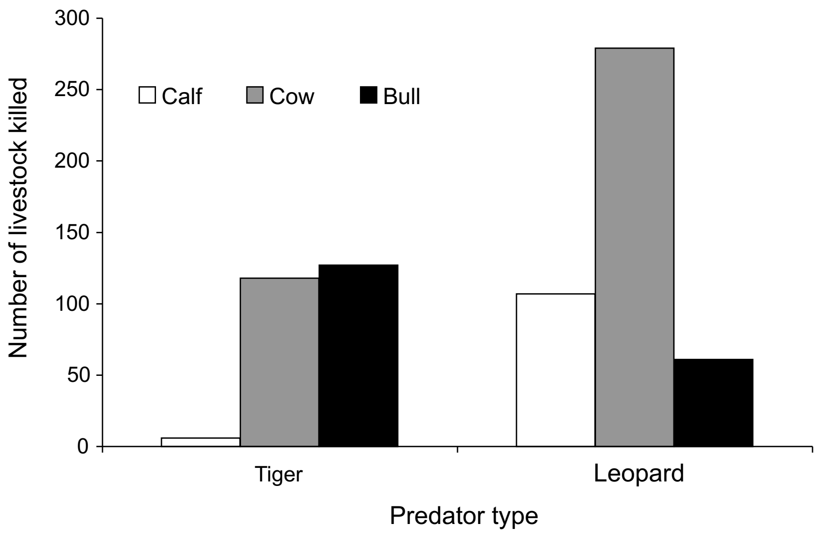

Fig. 2 – The number of cattle, partitioned into calves, cows and bulls, killed by tigers and leopards in 2004 and 2005 according to reports verified under the tiger compensation fund.

3.3. *Changes in frequency of predation with season*

Carnivores killed livestock throughout the year, but some differences in the number of livestock killed by predators compared to the expected kill frequencies were detected (Fig. 3). Frequency of kills by tigers and leopards were reasonably consistent throughout much of the year, with no differences detected between the observed and expected frequency for either predator, although the apparent increase in kills in July and August were on the margin of significance (Fig. 3a and b). There were more kills by snow leopards in June ($X^2 = 9.25$, $P = 0.002$) and July ($X^2 = 15.02$, $P = 0.0001$; Fig. 3c). For much of the year, including the winter months (October–January), no kills attributed to snow leopards were reported (Fig. 3c). More kills than expected were reported for bear in September ($X^2 = 30.5$, $P < 0.0001$) and October ($X^2 = 16.7$, $P < 0.0001$), with half of all kills reported for the year occurring in these months (Fig. 3d). Overall, livestock predation by all predators combined was greater than expected ($P < 0.0001$ for each month) from July to September (Summer–Autumn), with about 43% of kills reported in these three months, and lower than expected ($P < 0.0001$ for each month) in the six months from December through to April (Winter–Spring), during which time less that 30% of all kills occurred (Fig. 3e).

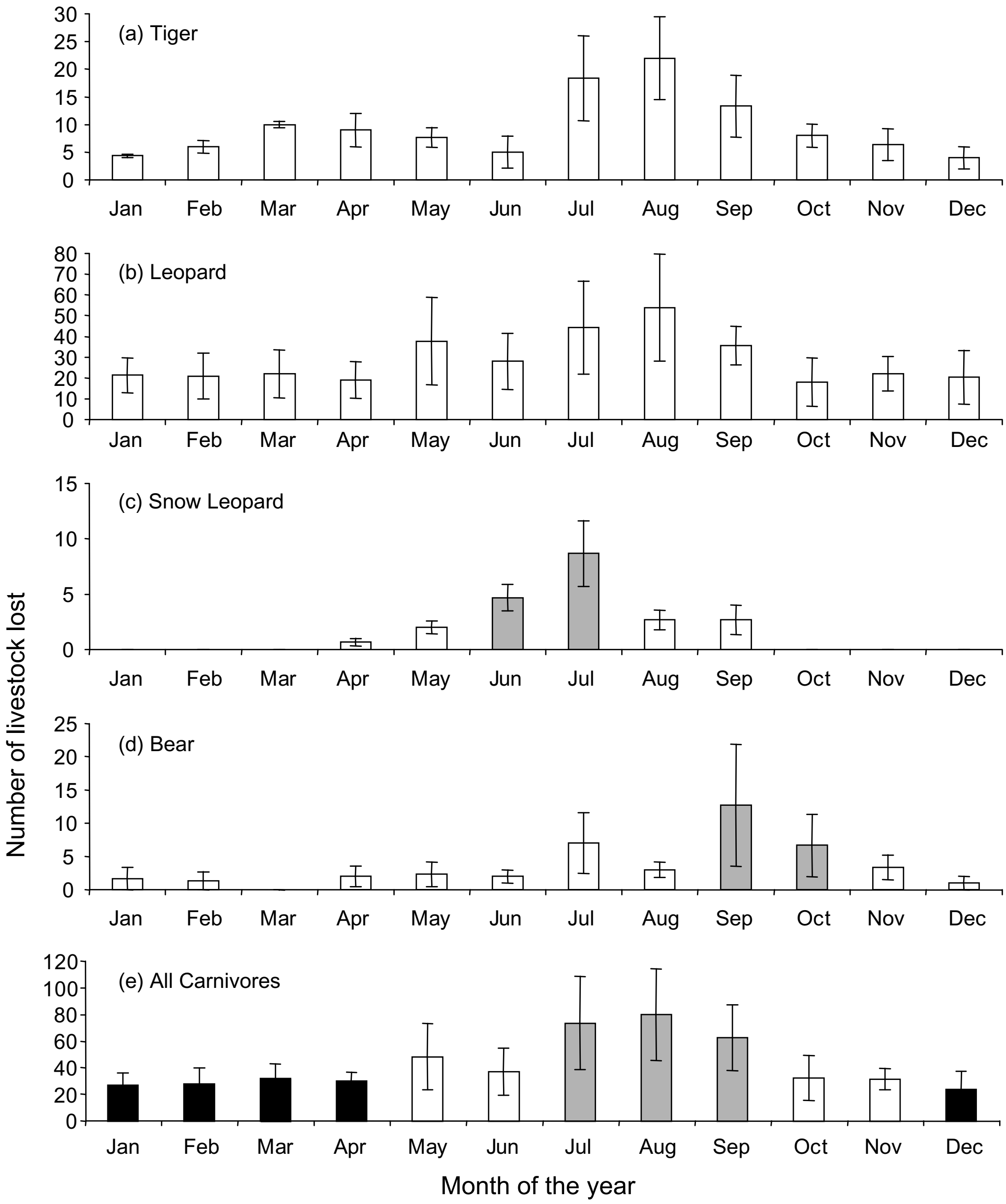

Fig. 3 – Number of livestock killed in each month of the year by (a) tigers, (b) leopards, (c) snow leopards, (d) Himalayan black bears and (e) all predators combined in 2004 and 2005 according to reports verified under the tiger compensation fund. Grey bars show those months where numbers of kills were significantly greater than expected and black bars those months where numbers of kills were significantly fewer than expected according to Chi-square analyses.

3.4. *Regional differences in predation*

Bhutan is divided into 20 administrative districts (Fig. 4a), 18 of which reported livestock predation (Fig. 4b). Considering all predation events, districts in northern and central Bhutan lost the greatest numbers of livestock, with Lhuentse, Trashigang, Wangdue, and Trashiyangtse accounting for 601 (47%) of the total livestock predated (Fig. 4b). Tiger kills were reported from 16 of the 20 dzongkhags, and nearly a quarter of these (22%, or 67 kills) were reported from Trongsa (Fig. 4c). Three more districts each reported between 10 and 20% of all kills attributed to tigers, and the remaining kills were distributed across a further 12 dzongkhags (Fig. 4c). Leopard kills were also reported in 16 districts (Fig. 4d), with the greatest proportion (17%) reported from Lhuentse. A further four dzongkhags each reported between 10 and 15% of kills by leopards (Fig. 4d). Snow leopard kills were reported in four dzongkhags, with 22 of the 25 kills (88%) being reported from Gasa in the extreme north of Bhutan (Fig. 4e). Bear kills were reported in 10 dzongkhags, with three of these (Bumthang, Thimphu and Trashiyangtse) accounting for 68% of kills (Fig. 4f).

The ratio of reported kills to relative abundance of each livestock type within each dzongkhag (Fig. 5) provides an indication of livestock predation 'hotspots' in Bhutan (Fig. 6). All hotspots are located in northern Bhutan, with Gasa, Thimphu

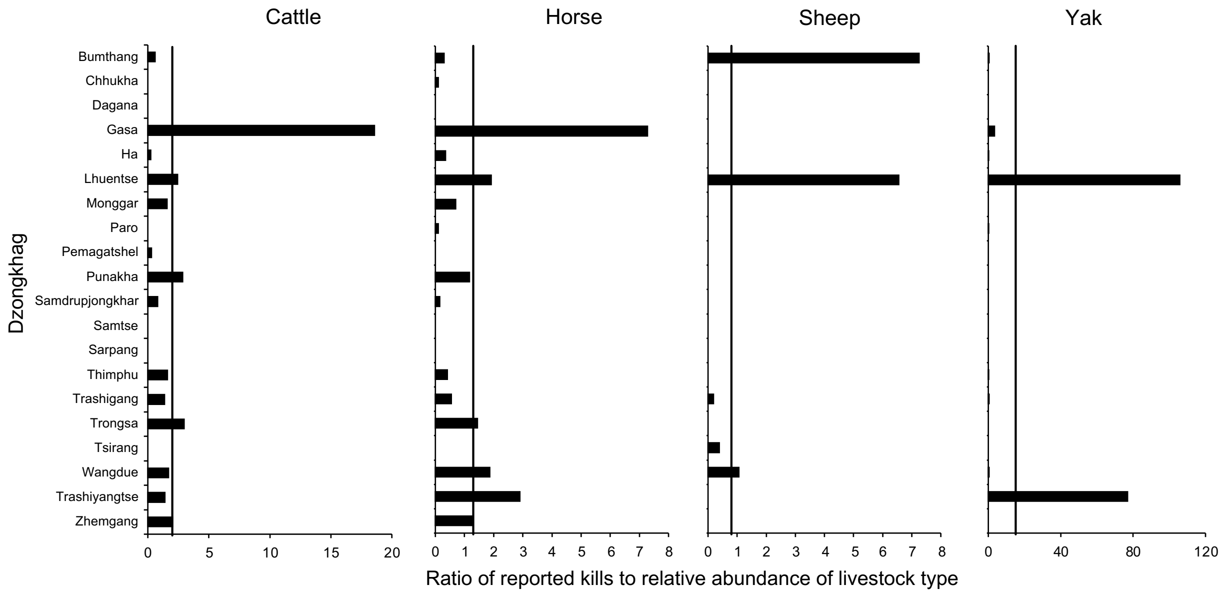

Fig. 4 – The ratio of reported livestock kills to the relative abundance of livestock types within each dzongkhag, according to reports verified under the tiger compensation fund between 2004 and 2005, and livestock census data from RGoB (2000). For each livestock type, the vertical black line indicates the average number of kills across the 20 dzongkhags that comprise the Kingdom of Bhutan.

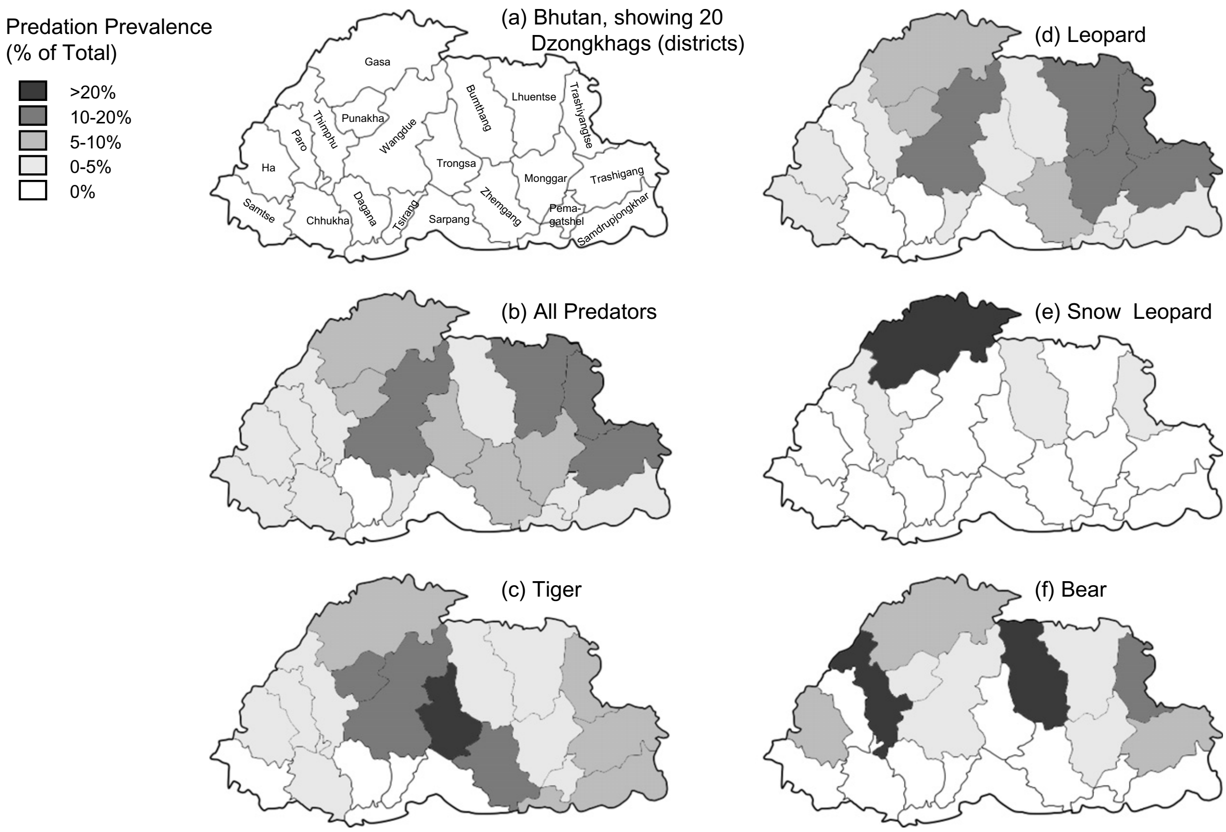

Fig. 5 – The Kingdom of Bhutan, showing (a) the 20 dzongkhags (districts); and livestock predation prevalence (kills per district as a percentage of the total number of kills) for (b) all predators combined, (c) tigers; (d) leopards, (e) snow leopards, and (f) Himalayan black bears, between 2003 and 2005.

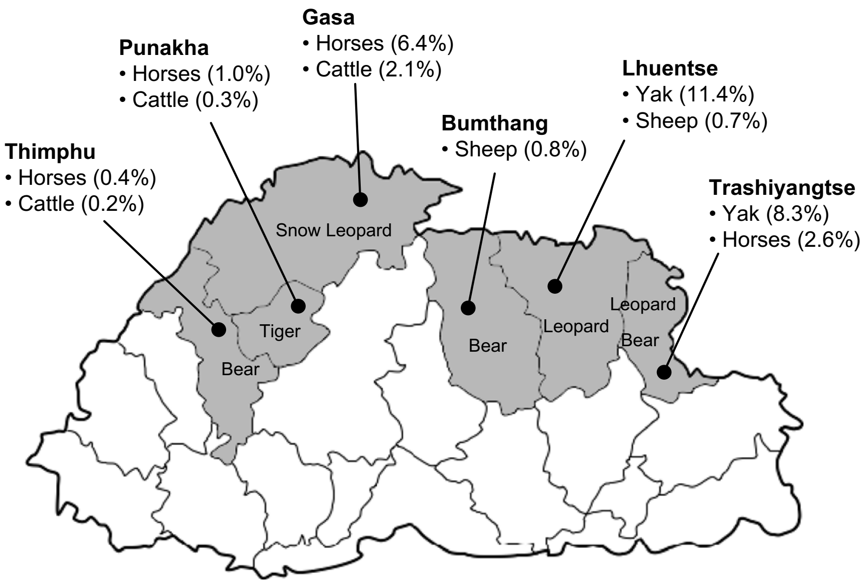

Fig. 6 – The six dzongkhags identified as 'livestock predation hotspots' based upon the ratio of reported kills to relative abundance of livestock (Fig. 4), predation prevalence (Fig. 5) and the proportion of livestock lost per year to predation. Major prey and their predators that contributed most to hotspot status are indicated.

and Punakha identified as hotspots for cattle predation, Gasa, Punakha, Thimphu and Trashiyangtse identified as hotpots for horse predation, Bumthang and Lhuentse identified as hotspots for sheep predation, and Lhuentse and Trashiyangtse identified as hotspots for yak predation (Figs. 5 and 6).

In terms of percentage of the combined herd lost in each dzongkhag, the greatest losses occurred in northern Bhutan. For some livestock types, loses to predators were substantial (Table 1). For example, over the 2 years of our study, Gasa lost approximately 6.4% of its horse population and 2.1% of its cattle population annually (Table 1; Fig. 6), Lhuentse lost approximately 11.4% of its yak population, and Trashiyangtse lost 8.3% of its yak population and 2.6% of its horse population annually (Table 1; Fig. 6). Districts in southwestern Bhutan

Table 1 – The percentage of the estimated regional herd of cattle, yak, horse and sheep in each dzongkhag that was lost annually to predation in 2004 and 2005 according to reports verified under the tiger compensation fund

Dzongkhag (region)	Percentage lost of estimated regional herd (per year)				
	Cattle	Yak	Horse	Sheep	All livestock
Gasa	2.1	0.4	6.4	0.0	1.05
Trashiyangtse	0.2	8.3	2.6	0.0	0.52
Lhuentse	0.3	11.4	1.7	0.7	0.47
Punakha	0.3	0.0	1.0		0.38
Trongsa	0.3		1.3	0.0	0.34
Zhemgang	0.2		1.1	0.0	0.33
Wangdue	0.2	0.0	1.7	0.1	0.26
Monggar	0.2	0.0	0.6	0.0	0.21
Bumthang	0.1	0.0	0.3	0.8	0.18
Trashigang	0.2	0.0	0.5	0.0	0.16
Thimphu	0.2	0.0	0.4	0.0	0.10
Samdrupjongkhar	0.1	0.0	0.1	0.0	0.09
Ha	0.0	0.0	0.3	0.0	0.04
Pemagatshel	0.0		0.0	0.0	0.03
Paro	0.0	0.0	0.1	0.0	0.01
Tsirang	0.0		0.0	0.0	0.00
Chhukha	0.0		0.1	0.0	<0.01
Samtse	<0.01		0.0	0.0	<0.01
Dagana	0.0		0.0	0.0	0.00
Sarpang	0.0		0.0	0.0	0.00
All Dzongkhags	0.12	0.07	0.89	0.16	0.16

Dzongkhags are ordered according to percentage of all livestock lost. Numbers of livestock in each dzongkhag that were used to calculate values in the table were taken from RGoB (2000).

lost fewer livestock (Fig. 4b), and seven of the eight dzongkhags in that region of the country suffered the lowest percentage loss of their livestock herd (Table 1). In particular, Tsirang, Chhukha and Samtse had minimal losses, and two districts, Dagana and Sarpang lost none (Table 1; Fig. 4).

The only significant correlation between predation (by all predators combined) and forest cover, density of each livestock type and human population density (by dzongkhag) was a strong positive correlation with horse density ($r = 0.63$, $P < 0.01$). Leopard predation was also strongly correlated with horse density ($r = 0.68$, $P < 0.01$, and bear predation was more weakly correlated with yak density ($r = 0.48$, $P < 0.05$). Predation events by some individual species were also correlated with percentage of forest cover in each dzongkhag; snow leopard predation was negatively correlated with the percentage of closed forest ($r = -0.64$, $P < 0.01$), and a negative correlation between bear predation and closed forest was on the margin of significance ($r = -0.44$, $P = 0.05$). Cattle density was positively correlated ($R = 0.60$, $P < 0.01$) and yak density negatively correlated ($R = -0.55$, $P < 0.02$) with the percentage of open forest. There were no relationships between human population density and predator activity, but there was significant correlations between human population density and cattle density ($R = 0.60$, $P < 0.01$).

Using multiple regression of the prevalence of predation activity (kills/km^2/year; all predators combined) against % of closed and open forest cover, density of each livestock type, and human population density in each dzongkhag, the model that described the greatest variance in overall predation activity ($R^2 = 0.60$, $P = 0.002$) was characterized by a positive association with horse density ($P = 0.0004$), and negative associations with cattle density ($P = 0.031$) and yak density ($P = 0.025$). The best model describing livestock predation by leopards ($R^2 = 0.75$, $P = 0.0002$) included a positive relationship with horse density ($P = 0.0001$), and negative relationships with cattle density ($P = 0.036$) and yak density ($P = 0.003$). The best snow leopard predation model ($R^2 = 0.63$, $P = 0.001$) included negative associations with closed forest cover ($P = 0.0002$) and yak density ($P = 0.03$). There were no regression models that could adequately explain predation by tigers or bears.

4. Discussion

4.1. *Prey size and preference*

All the carnivores in our study will take a range of prey sizes from small to large mammals, but larger prey are preferred, with the upper size limit of prey dictated to a degree by the size of the predator. So, the large and powerful tiger (100–260 kg; Nowak, 1999) typically takes considerably larger (50–100 kg) wild prey than the leopard, which weighs 30–90 kg (Nowak, 1999) and takes prey in the range of 25–50 kg (Seidensticker, 1976). For example, in Chitwan, Nepal, the average weight of wild prey species taken was 97 kg for tiger and 28 kg for leopard (Seidensticker, 1976; Seidensticker and McDougal, 1993). Similarly, leopards in India take prey generally weighing less than 50 kg (Johnsingh, 1992), while prey taken by tigers there average about 82 kg (Biswas and Sankar, 2002). Our results for the size differences in domestic prey taken by tigers and leopards match trends in these previous studies of wild predation. In our study, tigers killed more large animals than expected, including bull cattle that can weigh up to 300 kg. Calves and sheep, which weigh around 45 kg, made up a significant part of leopard kills. Bulls, by comparison, comprised only 3% of leopard kills.

Snow leopards killed mostly horses and yaks, a trend that is undoubtedly related to the distribution and abundance of these predators. Cattle are not reared in the high mountains where snow leopards occur; rather, people in that region depend on yaks for subsistence, and horses for transporting goods. Bears were reported to have predated almost all livestock types and classes, but because they are more omnivorous than the other predators in this study, it is possible that some claimed attacks were actually mistaken reports of bears scavenging on the carcasses of animals that had died from other causes, despite the care taken to exclude scavenging events from compensation claims. Significantly greater predation by bears was reported in September and October, which follows the peaks in June–August for other predators, an observation that would support scavenging by bears on carcasses killed by one of the other predators at an earlier time.

Leopard kills accounted for 70% of the total kills over the two years of our study. Most likely, this is related to leopards being relatively abundant and widespread in Bhutan. Increased predation by leopards is also compounded by their habit of engaging in 'surplus killing', something we observed in three different incidents during the study. A leopard killed 10 sheep in one night at Phobji (Wangdue, central Bhutan), another killed 22 sheep in Gangtey (Wangdue), and a third animal killed 11 sheep in one night at Khoma (Lhuentse, north eastern Bhutan). Surplus killing is not uncommon among cats and other large carnivores (for examples see Kruuk, 1972; Fox and Chundwat, 1988; Linnell et al., 1999; Odden et al., 2002).

Our data on the relative involvement of each predator in livestock killings is very similar to the data gathered by Wang and Macdonald (2006) for Jigme Singye Wangchuck National Park in central Bhutan. In that study, leopards were the dominant livestock predators (52%), followed by tigers (26%), with a relatively small involvement by bears (8%). Wang and Macdonald (2006) also reported wild dog predation in their study, but because this was not covered by the TCF, we have no countrywide data on wild dog predation.

Amongst livestock types, our data suggest that horses are the most vulnerable to attack from wild mammalian predators. Although cattle losses were substantial, this is consistent with the abundance of cattle in the landscape, which generally number in the thousands in each dzongkhag, for a combined 'national herd' of more than 320,000 animals (RGoB, 2000). By comparison, there are only about 23,000 horses in Bhutan, but horses comprised about a third of all livestock kills. Generally, horses have lower economic potential compared with cattle, and are often left un-tethered at night, the time when most of the predators in our study prefer to hunt. Furthermore, horses are typically left to graze untended in fields or forest when they are not being used for portage, increasing their vulnerability to predation. Mishra

(1997) also found that horses in Indian trans-Himalaya were preyed upon significantly more than would be expected from their abundance, and he attributed this to the herding practice of allowing horses to graze free-range during summer months.

4.2. *Seasonality of predation*

Our data show that more livestock were lost during summer and autumn (July through September) compared with other times of the year. This is a time when cropping agriculture is at its peak, with maize weeding and harvesting and paddy transplanting and weeding taking place during these months. During this season, livestock are more likely to be left free to graze and browse in the forest due to the diminished human resources available to guard livestock. In both Italy and France, the highest incidence of domestic sheep predation by wolves occurred among untended, free ranging flocks (Ciucci and Boitani, 1998; Espuno et al., 2004). It is possible that untended livestock in Bhutan are similarly at higher risk of attack; several authors point towards inadequate herding practices as a large contributor to livestock attack throughout the Himalayan region (Oli et al., 1994; Mishra, 1997; Ikeda, 2004; Namgail et al., 2007), including Bhutan (Wang and Macdonald, 2006).

By comparison to predation by tigers and leopards, predation by snow leopards peaked earlier during the summer months of June and July, and spanned a limited period from April through to September, with no predation reported at other times. The summer period corresponds with livestock being moved to higher elevation (late April) to graze pasture, being returning to winter pastures at lower elevations in October (WWF and NCD, 2004; Tshering Nidup, pers. comm.).

4.3. *Geographical differences*

In some dzongkhags, predation of horses (principally by tigers and leopards) corresponded roughly to the proportion of horses kept in each district, but in others, the ratio of reported kills to relative abundance of horses was high (Fig. 4). Generally, predation by all predators combined was strongly correlated with the density of horses. In Bhutan, about 42% of farm households are more than 1 hours walking distance to the nearest motorable road (RGoB, 2005 b). For these households horses are the main means of transportation. Several remote dzongkhags (Gasa, Lhuentse, Trashigang, Trashiyangtse, Wangdue and Zhemgang) do not have roads negotiable by motor vehicles, and these districts reported more horse losses relative to abundance (see Fig. 4) than those where motor transportation is more common. Losses in some dzongkhags were considerable, representing as much as 1–7% of the standing horse population; presumably translating to serious economic loss for some individuals. Losses of other livestock types in some areas were also substantial, with more than 10% of yaks and 2% of cattle lost in some dzongkhags (Table 1).

In other parts of the world, livestock losses of the magnitude we report can lead to substantial economic hardship and increased human–wildlife conflicts. For example, Jackson and Wangchuk (2004) reported that a 12% loss of livestock to snow leopard predation in Hemis National Park in Himalayan India had significant economic implications for villagers in that region, and led to retaliatory killing of snow leopards and a breakdown of relationships between villagers and park authorities. In villages near Serengeti National Park in Tanzania, livestock losses of 4.5% to a range of predators equated to a financial loss of 20% (sometimes considerable more) of the annual cash income for local families (Holmern et al., 2007). In Nepal, Oli et al. (1994) determined that a loss of 2.6% of total livestock holdings represented almost a quarter of average household *per capita* income. In these cases, retaliatory killings by people for losses were common. In some parts of Bhutan, unacceptable levels of livestock predation are also occurring. Wang and Macdonald (2006) showed that about 2.3% of livestock are lost annually to predators in Jigme Singye Wangchuck National Park in central Bhutan, and our data indicate that these sorts of predation rates are occurring across larger geographical areas, particularly in remote dzongkhags in northern Bhutan. If the current trend of increasing livestock losses (NCD, 2004) continues across Bhutan into the future, we could expect similar human–wildlife conflicts to emerge. Although the predominantly strong Buddhist religious ethic in Bhutan may curb widespread retaliatory killings of wildlife (Seeland, 2000; NCD, 2004), frustration at losing livestock to predation does translate to acts of retaliation, and resentment towards wildlife is apparently on the increase (NCD, 2004). A survey by Wang et al. (2006) of attitudes of farmers to livestock loss to predators in Jigme Singye Wangchuck National Park showed that 68% of respondents "expressed a strong desire to exterminate problem wildlife".

There were no significant positive relationships between frequency of predation and livestock density for cattle, yak or sheep in each dzongkhag, suggesting that the density of these livestock did not have much influence on the likelihood of losing these stock types to predators. Indeed, in some cases, high densities of cattle and yak were associated with lower predation rates, for example, in the case of leopard kills being negatively correlated with cattle and yak density. Although this might indicate a hunting strategy of pursuing smaller or more dispersed cattle herds, it more likely reveals an underlying avoidance by predators of areas where human population density is greatest, because cattle and human densities were strongly correlated with one another.

Bears and snow leopard kills occurred more often in northern dzongkhags where closed forest cover is much reduced, giving way to open alpine meadows at higher elevations in this part of Bhutan, and both of these species primarily killed yaks and horses that are the most common livestock types in these districts. By comparison, tiger and leopard kills were geographically widespread, and did not have any simple relationships with the percentage of either open or closed forest cover, or with human population density *per se*.

In general, there were few relationships between livestock holdings and predation rates, suggesting that areas of high predation are not necessarily related to high livestock density, except perhaps where horses are concerned. However, we did identify 'predation hotspots' where predation of livestock seemed disproportionately higher than livestock abundance and density would predict. These are all located in the remote mountainous northern regions of Bhutan. The northern part of Bhutan is characterized by high elevation alpine grasslands and sparsely populated by semi-nomadic livestock herders. Because of the nomadic lifestyle, where cattle and yak are moved seasonally between high elevations in summer and lower elevations in winter (Moktan et al., 2006), there is little infrastructure available for stock protection, and stock are more likely to be free range during the non-winter months. Competition between livestock and native herbivores is probably also heightened in this region, perhaps necessitating that carnivores prey on the abundant livestock that have replaced native herbivores in some areas. Mishra et al. (2001) document widespread overstocking of the rangelands of the trans-Himalayan region of India and show that this can lead to reduction in native herbivore numbers (Mishra et al., 2001) which in turn has been linked to increased predation of livestock by wild carnivores (Bagchi and Mishra, 2006). More research on livestock numbers, grazing pressure and livestock husbandry practices in the northern rangelands of Bhutan is warranted in order to understand more fully the reasons for the high levels of predation we observed there.

5. Conclusions

Human–wildlife conflict is a complex facet of wildlife management, and in Bhutan as elsewhere, careful management will be required if the duel goals of wildlife conservation and economic livelihood for pastoralists are to be met. Wang et al. (2006) showed that farmers in central Bhutan were interested in offering ways that human–wildlife conflict can be reduced, but were frustrated by livestock predation which in turn cultivated an alarmingly high support for extermination of problem wildlife. Our aim in this paper was to provide knowledge that can help government agencies in Bhutan formulate countrywide strategies for mitigating livestock losses, and ultimately, help conserve predator populations through reduction in human–wildlife conflicts.

Our data show that leopards are the dominant livestock predator in Bhutan, a factor probably related to their numerical abundance compared to other predators covered by the TCF. Leopards probably prefer to hunt the smaller or more easily tackled livestock, and in our study they were responsible for almost all of the calf and foal kills, most of the sheep and horse kills, and more than half of cow kills. Therefore, measures aimed at reducing livestock predation in Bhutan should focus on leopards as the key predator, and cows, horses, sheep and juvenile livestock as the key targets. In areas where tigers are prevalent, our data suggest that measures should be taken to protect the larger and more valuable livestock such as bull cattle, although presumably, in the absence of larger livestock, tigers would switch to other available livestock types.

Generally, horses are the most vulnerable livestock type, a factor that is probably related in part to them being allowed to graze unprotected when not being used for their primary purpose of transportation. Horse kills formed a large part (about one third) of all livestock kills reported, and the number of horses lost was greatly disproportionate to the number of horses kept in each district compared with cattle, so programs that aim to encourage animal husbandry methods that would protect horses from predation would likely lead to a significant decline in overall livestock predation rates by predators across Bhutan. Our analyses suggest that geographical and seasonal affects were also at play, so programs aimed at encouraging greater vigilance against livestock predators in northern dzongkhags, where predation was greatest, and during the summer months when cropping agriculture is at a peak and livestock are less well guarded, would also be beneficial in curbing livestock losses.

Finally, work in Bhutan (Wang et al., 2006) and elsewhere (e.g. Oli et al., 1994) demonstrate that the success of any predation mitigation measures require the full engagement of farmers in wildlife management decisions, concurrent with the implementation of strategies aimed to educate the public about the value of nature conservation. Lessons learned in other programs aimed at managing human–wildlife conflicts around the world should therefore be useful in formulating a response to the problem in Bhutan.

Acknowledgements

We would like to thank the Royal Government of Bhutan for the opportunity to undertake this work. Thanks are due to Dr. Sangay Wangchuk and Mr. Sherub, (Nature Conservation Division), Mr. Kinzang Namgay, (Country Representative, World Wide Fund for Nature), and Mr. Chado Tenzin (FAO Bhutan) for their guidance and unfailing support to the compensation scheme. We would like to also acknowledge the support of the verifying staff (community leaders, veterinarians, foresters and park staff) for helping in data collection, investigation and verification in the field. Dr. Andrew Boulton (University of New England) provided statistical guidance, and an anonymous reviewer provided valuable advice for improving earlier versions of this manuscript. Finally, we would also like to thank WWF Bhutan, the US Fish and Wildlife Foundation, and Save the Tiger Fund for their sponsorship of the tiger conservation fund; and Ms. Nancy Abraham for her personal assistance with financing the compensation scheme in the Bhutan.

REFERENCES

Allen, L.R., Sparkes, E.C., 2001. The effect of dingo control on sheep and beef cattle in Queensland. Journal of Applied Ecology 38, 76–87.

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

Biswas, S., Sankar, K., 2002. Prey abundance and food habit of tigers (*Panthera tigris tigris*) in Pench National Park, Madhya Pradesh, India. Journal of Zoology 256, 411–420.

Ciucci, P., Boitani, L., 1998. Wolf and dog depredation on livestock in central Italy. Wildlife Society Bulletin 26, 504–514.

Espuno, N., Lequette, B., Poulle, M.L., Migot, P., Lebreton, J.D., 2004. Heterogeneous response to preventive sheep husbandry during wolf recolonization of the French Alps. Wildlife Society Bulletin 32, 1195–1208.

Fox, J.L., Chundwat, R.S., 1988. Observations of snow leopard stalking, killing and feeding behavior. Mammalia 52, 137–140.

Govil, K., 1999. Forest resources of Bhutan – country report. FAO Forest Resources Assessment Working Paper No. 14, Food and Agriculture Organisation of the United Nations, Rome.

Holmern, T., Nyahongo, J., Røskaft, E., 2007. Livestock loss caused by predators outside the Serengeti National Park, Tanzania. Biological Conservation 135, 518–526.

Hussain, S., 2003. The status of the snow leopard in Pakistan and its conflict with local farmers. Oryx 37, 26–33.

Ikeda, N., 2004. Economic impacts of livestock depredation by snow leopard *Uncia uncia* in the Kanchenjunga Conservation Area, Nepal Himalaya. Environmental Conservation 31, 322–330.

Jackson, R.M., Wangchuk, R., 2004. A Community-based approach to mitigating livestock depredation by snow leopards. Human Dimensions of Wildlife 9, 307–315.

Johnsingh, A.J.T., 1992. Prey selection in three large sympatric carnivores in Bandipur. Mammalia 56, 517–526.

Kolowski, J.M., Holekamp, K.E., 2006. Spatial, temporal, and physical characteristics of livestock depredations by large carnivores along a Kenyan reserve border. Biological Conservation 128, 529–541.

Kruuk, H., 1972. Surplus killing by carnivores. Journal of Zoology, London 166, 233–244.

Linnell, J.D.C., Odden, J., Smith, M.E., Aanes, R., Swenson, J.E., 1999. Large carnivores that kill livestock: do problem individuals really exist? Wildlife Society Bulletin 27, 698–705.

Maikhuri, R.K., Nautiyal, S., Rao, K.S., Chandrasekhar, K., Gavali, R., Saxena, K.G., 2000. Analysis and resolution of protected area-people conflicts in Nanda Devi biosphere reserve, India. Environmental Conservation 27, 43–53.

Mazzolli, M., Graipel, M.E., Dunstone, N., 2002. Mountain lion depredation in southern Brazil. Biological Conservation 105, 43–51.

Michalski, F., Boulhosa, R.L.P., Faria, A., Peres, C.A., 2006. Human–wildlife conflicts in a fragmented Amazonian forest landscape: determinants of large felid depredation on livestock. Animal Conservation 9, 179–188.

Mishra, C., 1997. Livestock depredation by large carnivores in the Indian trans-Himalaya: conflict perceptions and conservation prospects. Environmental Conservation 24, 338–343.

Mishra, C., Prins, H.H.T., Van Wieren, S.E., 2001. Overstocking in the trans-Himalayan rangelands of India. Environmental Conservation 28, 279–283.

Moktan, M.R., Norbu, L., Nirola, H., Chhetri, D.B., Rai, T.B., Rinchen, 2006. Migratory cattle grazing: an ecosystem approach to livelihood. Bhutan Journal of Renewable Natural Resources 2, 18–28.

Musiani, M., Mamo, C., Biotani, L., Callaghan, C., Cormack Gates, C., Mattei, L., Visalberghi, E., Breck, S., Volpi, G., 2003. Wolf depredation trends and the use of fladry barriers to protect livestock in western North America. Conservation Biology 17, 1538–1547.

Myers, N., Mittermeler, R.A., Mittermeler, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.

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

NCD, 2001a. Bomdelling Wildlife Sanctuary: Conservation Management Plan July 2001–June 2007, Nature Conservation Division, Department of Forestry Services, Ministry of Agriculture, Royal Government of Bhutan, Thimphu, Bhutan.

NCD, 2001b. Thrumshingla National Park: Conservation Management Plan 2002/2003–2006/07, Nature Conservation Division, Department of Forestry Services, Ministry of Agriculture, Royal Government of Bhutan, Thimphu, Bhutan.

NCD, 2003. Jigme Singye Wangchuck National Park: Conservation Management Plan, July 2003–June 2007, Jigme Singye Wangchuck National Park, Nature Conservation Division, Department of Forests, Ministry of Agriculture, Thimphu, Bhutan.

NCD, 2004. Bhutan Biological Conservation Complex: A Landscape Conservation Plan – A Way Forward, Nature Conservation Division, Department of Forests, Ministry of Agriculture with support from WWF Bhutan Program, Thimphu, Bhutan.

Nowak, R.M., 1999. Walker's Mammals of the World, sixth ed. The Johns Hopkins University Press, Baltimore, USA. p. 2160.

Odden, J., Linnell, J.D.C., Moa, P.F., Herfindal, I., Kvam, T., Andersen, R., 2002. Lynx depredation on domestic sheep in Norway. Journal of Wildlife Management 66, 98–105.

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

Patterson, B.D., Kasiki, S.M., Selempo, E., Kays, R.W., 2004. Livestock predation by lions (*Panthera leo*) and other carnivores on ranches neighboring Tsavo National Parks, Kenya. Biological Conservation 119, 507–516.

Polisar, J., Maxit, I., Scognamillo, D., Farrell, L., Sunquist, M.E., Eisenberg, J.F., 2003. Jaguars, pumas, their prey base, and cattle ranching: ecological interpretations of a management problem. Biological Conservation 109, 297–310.

RGoB, 2000. Renewable natural resources statistics of Bhutan. Ministry of Agriculture, Royal Government of Bhutan, Thimphu, Bhutan.

RGoB, 2005b. Population and housing census of Bhutan 2005. Office of the Census Commissioner, Thimphu, Bhutan.

RGoB, 2005a, The Annual Report Presented by Prime Minister to the 83rd Session of the National Assembly on June 03, 2005, Cabinet Secretariat, Thimphu, Bhutan.

Sangay, 2006. Tiger (*Panthera tigris*) and its conservation efforts in the Kingdom of Bhutan. Master of Natural Resources Thesis, The University of New England, Armidale NSW, Australia.

Sangey, W., 2000. National anti-poaching strategy of Bhutan. Unpublished report to the Nature Conservation Division, Department of Forestry Services, Ministry of Agriculture, Thimphu, Bhutan.

Seeland, K., 2000. National park policy and wildlife problems in Nepal and Bhutan. Population and Environment 22, 43–62.

Seidensticker, J., 1976. On the ecological separation between tigers and leopards. Biotropica 8, 225–234.

Seidensticker, J., McDougal, C., 1993. Tiger predatory behavior, ecology and conservation. In: Dunstone, N., Gorman, M.L. (Eds.), . In: Mammals as Predators: The Proceedings of an Symposium Held by the Zoological Society of London and the Mammal Society: London, 22nd and 23rd November 1991. The Zoological Society of London, Clarendon Press, Oxford, UK, pp. 105–125.

Stahl, P., Vandel, J.M., Herrenschmidt, V., Migot, P., 2001. Predation on livestock by an expanding reintroduced lynx population: long-term trend and spatial variability. Journal of Applied Ecology 38, 674–687.

Wang, S.W., Macdonald, D.W., 2006. Livestock predation by carnivores in Jigme Singye Wangchuck National Park, Bhutan. Biological Conservation 129, 558–565.

Wang, S.W., Lassoie, J.P., Curtis, P.D., 2006. Farmer attitudes towards conservation in Jigme Singye Wangchuck National Park, Bhutan. Environmental Conservation 33, 148–156.

WWF & NCD, 2004. Study on Grazing, Cattle Migration and Tseri/Pangzhing in Thrumshingla National Park, WWF Bhutan Program/Nature Conservation Division, Thimphu, Bhutan.

Yom-Tov, Y., Ashkenazi, S., Viner, O., 1995. Cattle predation by the golden jackal *Canis aureus* in the Golan Heights, Israel. Biological Conservation 73, 19–22.