How do land-use practices affect human—elephant conflict in nepal?

Authors: Neupane, Dinesh, Johnson, Ronald L., and Risch, Thomas S.

Source: Wildlife Biology, 2017(1)

Published By: Nordic Board for Wildlife Research

URL: https://doi.org/10.2981/wlb.00313

Wildlife Biology 2017: wlb.00313
doi: 10.2981/wlb.00313

Subject Editor: Maria Johansson. Editor-in-Chief: Ilse Storch. Accepted 25 July 2017

How do land-use practices affect human–elephant conflict in Nepal?

Dinesh Neupane, Ronald L. Johnson and Thomas S. Risch

D. Neupane (dinesh.neupane@smail.astate.edu), Graduate program of Environmental Sciences, Arkansas State Univ., PO Box 847, State University, AR 72467, USA. – R. L. Johnson and T. S. Risch, Dept of Biological Sciences, Arkansas State Univ., AR, USA.

Asian elephants *Elephas maximus* are an endangered species and human–elephant conflict (HEC) is the major threat to their survival. HEC causes crop and property loss and occasionally results in the death of both humans and elephants in Nepal. Elephants are responsible for more than 40% of the human–wildlife conflict, 70% of the wildlife-caused human casualties, and a 25% loss in crop production in Nepal. Identification of the factors associated with elephant invasion can help mitigate conflict by allowing residents and representatives to address those factors. This study used face-to-face interviews in 1182 households in villages affected by elephants in southern Nepal using a structured questionnaire to understand how land-use practices are related to HEC regionally. Almost all (99%) of the surveyed houses had some damage from elephants within the past five years. A stepwise binary logistic regression showed that practices such as the growing of traditional crops (rice and large maize fields), maintaining bananas, and home alcohol production increase the chances of elephant attacks. Our data also revealed that HEC is most intense in winter months, when rice is harvested. People residing near protected areas had positive attitudes towards elephants, as they received economic benefits from ecotourism and improved mitigation practices such as electric fences. Changing some land-use practices could reduce HEC in the region. Therefore, alternative crops should be explored to reduce HEC in southern Nepal. Other management recommendations include moving fruit trees away from homes or fencing community orchards. Although home alcohol production is illegal in Nepal, those engaging in the practice should not ferment alcohol in their homes. Finally, growing bamboo on the edge of settlements would engage elephants and allow for a response to repel them before severe crop or house damage occurs.

Human–wildlife conflict is the major threat to the survival of megafauna and it occurs when requirements of wildlife overlap with people's needs and interests (Khounboline 2007). The major factor driving wildlife conflict is human population growth and the resource requirements associated with that growth. Human expansion transforms natural habitats of wildlife into human settlements and agricultural lands (Cordingley 2008).

Large mammals are particularly associated with conflict throughout much of the world. For example, animals like the African elephant *Loxodonta* spp., hyena *Crocuta* spp. and lion *Panthera* spp. are greatly impacted in Africa, whereas elephant *Elephas* spp., leopard *Panthera* spp., tiger *Panthera* spp., rhino *Rhinoceros* spp. and snow leopard *Panthera* spp. are involved in human–wildlife conflict in Asia. In North America, the primary large mammals associated with human conflict are wolves *Canis lupus* spp., coyote *C. latrans*, deer *Odocoileus* spp. and feral hogs *Sus scrofa* (Distefano 2005). Reducing this wildlife-related conflict is challenging, requiring huge economic investments to mitigate problems. Harvesting has been successful in the United States, especially to control over-populating animals like deer and feral hogs (Messmer 2009), but when it comes to animals at risk like elephants, lethal mechanisms are not appropriate.

Asian elephants *Elephas maximus* are listed as endangered by the IUCN, with populations decreasing due to habitat loss, human–elephant conflict (HEC), and poaching (Choudhury et al. 2008). Remaining populations are often fragmented and wildlife becomes displaced and thus encroaches on human settlements. The extent of HEC in south Asia is particularly devastating. HEC results in hundreds of human and elephant deaths annually (Perera 2009, Neupane et al. 2014). Although Nepal does not have a large population of elephants (109–142 individuals, DNPWC 2008), HEC rates are significant, and increasing in intensity, with 10 human and two elephant deaths annually (Neupane et al. 2014). Elephants typically enter settlements at night resulting in house damage and human injury

(Neupane et al. 2014). Large herds of mobile elephants tend to create problems seasonally in trans-border human settlements whereas small residential herds create damage locally in rural villages (Shrestha et al. 2007, Neupane et al. 2014). Neupane et al. (2017) in a smaller sample (n = 242) than this current study identified that 10% of households in villages neighboring wildlife refuges have experienced human injury or death over a five-year period.

Elephants are the most problematic large mammal species in Nepal, and responsible for more than 40% of the total human–wildlife conflict and 70% of wildlife-related human casualties (Bajimaya 2012). Up to a quarter of crop production is lost annually from elephants (Shrestha et al. 2007). The scope of the problem suggests that elephant damage to property may not be random. Identifying the risk factors associated with elephant encroachment such as land- and home-use practices that may be contributing to that encroachment is critical to formulating effective management plans.

Human land-use influences patterns of HEC in both Africa and Asia. Sitati et al. (2003) emphasized the importance of a detailed understanding of processes and patterns of elephant raiding incidences to implement the effective mitigation of conflict. Hoare (1999) identified an association between the land transformation from forest to agriculture purposes and elephant conflict. Distefano (2005) stated that small scale farming intensified the human–wildlife conflict in Kenya, whereas the growing of certain crops such as mango and sugarcane created favorable habitat for animals and influenced the distribution of wildlife in India (Vijayan and Pati 2002). The presence of fruit trees around the crop fields attracted elephants in Africa (Lahm 1996, Musyoki 2014).

Aim and hypotheses

This study aims to understand the type of land and home use practices that were associated with HEC in Nepal. We predicted that local residents would have differing attitudes towards elephants based on elephant damage, potential benefits of ecotourism, and presence of mitigation practices. We hypothesized that HEC is not random and that land- and home-use practices do affect the frequency and intensity of conflict in Nepal. Several hypotheses are addressed in the present study. First, we hypothesized that the type of agricultural crops (maize, rice, wheat, mustard) affect elephant encroachment to crop fields. Second, many rural properties in Nepal have home gardens, with fruit trees (banana, mango, jackfruit, sugarcane, litchi) and/or bamboo in close proximity to their houses. We hypothesize that the presence of fruit trees and/or bamboo in home gardens is associated with elephant attacks to houses. The third hypothesis states that the presence of specific house contents (e.g. stored grains, alcohol) influences elephant damage to households.

Methods

Study area

Nepal is one of the most densely populated countries in south Asia (180 persons per km^2, CBS 2014), and is geographically located between the lowlands of northern India and the Himalayas of southwest China. In a north–south direction, topographically Nepal is divided into mountains, hills, and the lowland Terai, the southern belt of flat plains. Nepal has two types of elephant herds: large mobile herds that regularly cross the border to and from India, and small residential herds that inhabit the remaining forest fragments (Velde 1997, Shrestha et al. 2007, Yonzon 2008). For the purpose of our study, it was useful to divide the Terai into three regions: eastern (ET), central (CT), and western (WT). Both ET and WT contain trans-border mobile routes for elephants, and HEC is primarily associated with these mobile herds. In contrast, CT contains only residential herds which cause lower levels of HEC (Yonzon 2008, Neupane et al. 2014). Eastern Terai contains one nationally protected forested area (Koshi Tappu Wildlife Reserve) and fragmented patches of community forests; CT contains two well-connected protected forests (Chitwan National Park and Parsa Wildlife Reserve) and dense community forests surrounding the protected areas; and WT has three larger protected areas (Banke National Park, Bardia National Park, and Shuklaphanta Wildlife Reserve) and good forest connectivity with Indian protected areas. This study focuses on eleven highly populated agricultural districts of the Terai (three districts each from ET and WT, and five districts from CT), where HEC are prevalent (Fig. 1) (Neupane et al. 2014).

Data collection

Participants

The households were selected from the elephant roaming regions in the Terai by visiting every 10th house we encountered in each village. We approached residents at their homes and only proceeded with the survey if the interviewee was over 18 years of age. During the survey, respondents were informed about the aim of the surveys and asked for their consent to conduct the surveys. All the respondents were asked if they would agree to participate in the survey; and no one refused.

Questionnaire

Prior to constructing the survey, we first conducted a pilot survey of local individuals and had focus group discussions with representatives from villages, community forests, and park officials in 2010. Residents indicated during the pilot study that elephants preferred traditional crops (rice, maize, wheat), garden fruit trees (banana, mango, jackfruit), and home garden plants (bamboo, broom grass). Similarly, residents informed Neupane that elephants were attracted to salt, and/or stored grains, and the smell of alcohol, and tended to damage the kitchen more than other parts of houses. Based on the information, questionnaire was constructed. We surveyed 1182 households (ET: 414, CT: 348, WT: 420) (Table 1) from 2012 to 2013 by way of face-to-face interviews using a structured questionnaire.

The questionnaire had two sections: general information about households and practices such as home alcohol production, types of agricultural crops grown, and types of fruit trees grown around the houses; and elephant-related issues

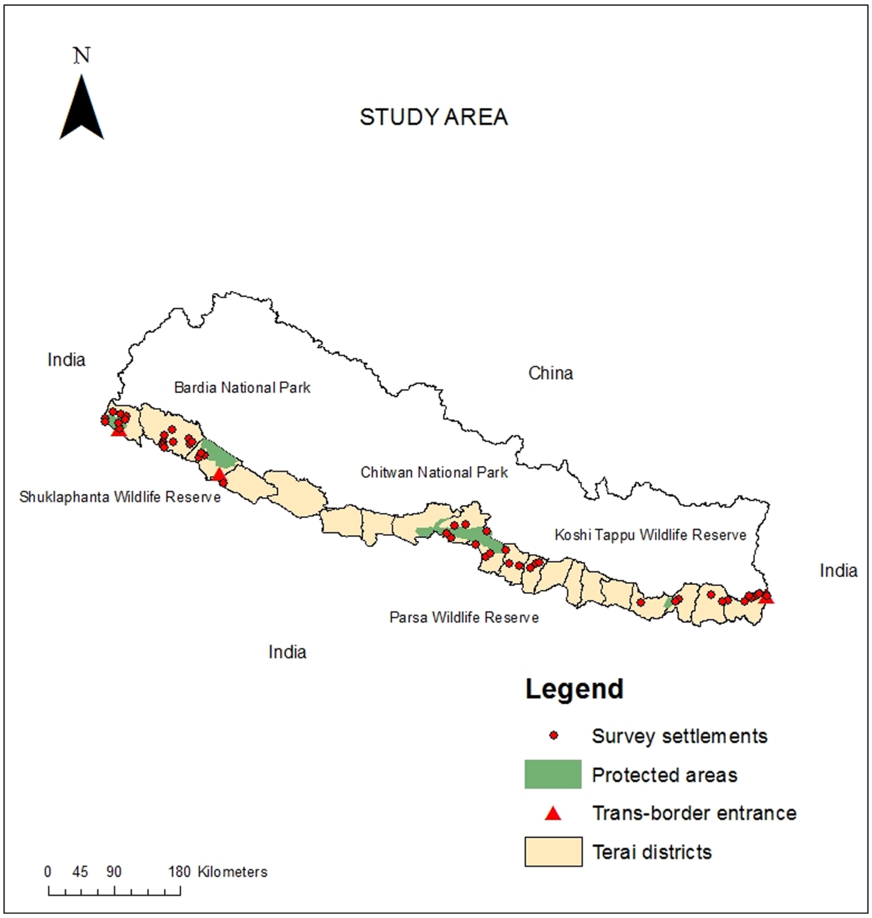

Figure 1. A map showing Nepal with boundaries of China and India, surveyed settlements, protected areas, and trans-border elephant entrance in the Terai.

such as intensity, frequency, and months of damage, and local mitigation measures employed to reduce HEC.

Respondents' socioeconomic background information was collected, including farm size (in Kattha; 1 Kattha = 0.034 ha). Respondents were asked if their farm production was sufficient or not for their annual subsistence. Households were designated as deficit (code: 0) or sufficient (code: 1), depending upon whether net food grains were bought or sold during the year. Home alcohol production was coded in a binary manner (yes = 1, no = 0). People were also asked if they grew fruit trees around their house (yes = 1, no = 0), and if so, asked to list the types of trees that they were growing. Each tree species was coded '1' if present and '0' if absent.

If households experienced damage (crop or property damage) from elephants in the past 5 years, they were coded as '1' (otherwise '0'). If households received home damage, we questioned if the kitchen was initially targeted.

People were asked to characterize the frequency of HEC locally as one of four levels: none, moderate, high and very high. If HEC was infrequent and up to a couple of times in a year, it was categorized as moderate. 'High' was defined if the elephant movement was seasonal and predictable; 'very high' indicated the damage was intense and elephant conflict was throughout the year. We asked residents to identify the month(s) when they experienced elephant damage, and also the crops that elephants raided over the last five years on their farms. People were also asked if they had any local electric fencing to defend against elephant movement (coded as 1 – yes, 0 – no). Respondents were also asked if they had received any financial benefit resulting from elephant conservation in their region directly or indirectly (coded as 1 – yes benefits, 0 – no benefits).

Statistical analyses

To determine the influence of land-use and home-use practices relative to HEC, we used binary logistic regression to develop the best predictive model to approximate how likely (or unlikely) the outcome was to occur associated with the presence of a particular variable. We used binary logistic regression for individual variables such as HEC frequency, type of elephant herd, electric fencing, and perceived economic benefit with crop or property damage. To generate our models, we included interaction terms between variables and used a stepwise approach so that variables or interactions with a p-value greater than 0.1 were removed from the model. We tested the probability of crop damage occurrence given the predictors: type of crops (rice, maize, wheat, and mustard), farm size and number of crops grown in a year.

Table 1. Summary of surveyed households (in percentage) with major sources of income, landholding in Kattha, food sufficiency status, and frequency of HEC in the Terai districts of Nepal. Deficit includes households where food grown is not sufficient for household needs; surplus represents households that produce enough food.

Variables	Eastern Terai	Central Terai	Western Terai	Total
Income source				
n*	413	346	419	1178
Farming	70.5	65.9	53.2	63
Business	8.5	7.2	10.0	8.7
Self-employed	6.5	7.8	8.1	7.5
Service	6.8	7.8	6.2	6.9
Student	3.6	1.4	9.5	5.1
Foreign labor	1.0	2.0	2.4	1.8
None	3.1	7.8	10.5	7.1
Landholding				
n*	413	346	420	1179
No land	2.9	1.4	1.0	1.8
0.1–10	25.9	37.6	42.6	35.3
10.1–20	33.4	33.5	25.0	30.4
20.1–60	33.9	24.9	24.8	28.0
60.1–100	3.1	2.0	5.2	3.6
>100	0.7	0.6	1.4	0.9
Food sufficiency				
n*	410	339	420	1169
Deficit %	51.3	49.1	54.8	46.0
Sufficient %	22.9	20.2	8.6	21.4
Surplus %	25.8	30.7	36.6	32.6
Frequency of HEC				
n*	414	348	420	1182
None	0.2	1.1	2.1	1.2
Moderate	11.1	20.7	22.4	17.9
High	22.7	29.0	26.4	25.9
Very high	65.9	49.1	49.0	55.0

*Sample size varies slightly based on the completion of survey responses.

Similarly, the probability of property damage was tested using the predictor: type of fruit trees (banana, mango and jackfruit), number of types of fruit trees grown, and alcohol production at home (yes or no). We also considered multicollinearity and test of model fit. The variance inflation factor (VIF) was used to determine multicollinearity. In a stepwise approach, we also eliminated variables and/or interactions with a VIF greater than 10 (Peeters et al. 2012, Sibanda and Pretorius 2012). The test of model fit was then performed using the Hosmer–Lemeshow goodness-of-fit test (Hosmer and Lemeshow 2000). χ^2 was used to determine the significance of final models, with alpha levels set at 0.05.

Elephant damage was distinguished as either crop or property damage. Damage variables lead to the negative attitude towards elephant conservation. Government investment in infrastructures such as the construction of electric fences and residents receiving economic benefits from conservation could lead to positive attitudes for those residents. Thus, four variables (percentages of households suffering from crop damage, households suffering from property damage, houses having an electric fence facility around the area, and households perceiving economic benefit from elephant conservation) were considered for exploratory factor analysis to understand the Terai-wide position of specific districts and regions in terms of conservation measures and damage variables. Factor analysis was also performed to draw a score plot based on these four variables. Factor analysis is a tool to summarize the data into factors by condensing the large sets of data based on their correlations (Hair et al. 2009), where a single factor acts as a variable. A factor analysis places the pairs of factors in a group (Riitters et al. 1995). Thus, our study grouped damage variables (crop and property damage) in one pair whereas conservation measures (electric fencing and economic benefit) were grouped as another pair.

Results

Socioeconomic characteristics of respondents

Most respondents surveyed (63%) relied on agriculture as their primary occupation for their incomes, with business ranking a distant second (9%). Over two-thirds of households surveyed in ET and CT relied on farming for their basic source of income to the family; this percentage decreased to half in WT (Table 1). Three-fourths of the households in the Morang and Sunsari districts (ET) and the Parsa District (CT) had farming as the major income. More than one-third of the families surveyed had small farms (< 10 Kattha, i.e. 0.34 ha), whereas only 4% of the families had large land holdings (> 100 Kattha, i.e. 3.38 ha, Table 1. Western Terai households in particular had small landholdings, on average, and over 77% of households were less than 20 Kattha (0.68 ha, Table 1). Half of the households surveyed overall did not raise enough food to meet their household needs, with that number rising to two-thirds of surveyed residents from Morang District (ET) (Table 1).

Districts of CT (14.2%) had more extensive electric fence facilities compared to those of WT (5.5%) and ET (3.4%) (Table 2). In addition to having high elephant damage in ET, there was low economic benefit received there from wildlife conservation through ecotourism or governmental agencies.

Human–elephant conflict

About one-fourth (27%) of the surveyed houses had experienced property damage and three-fourths experienced crop damage attributed to elephants (Table 2). Most households

Table 2. District-wise percentage of surveyed households experiencing crop damage, property damage, having electric fencing, and perceived economic benefit from wildlife conservation in the last five years (2007–2012).

District	Crop damage	Property damage	Electric fence	Conservation benefit
Bara (CT)	87.5	20.0	2.5	2.5
Bardia (WT)	80.3	31.2	98.4	23.0
Chitwan (CT)	70.7	16.4	95.7	30.7
Jhapa (ET)	75.0	41.8	61.3	4.5
Kailali (WT)	73.8	26.2	12.7	0.5
Kanchanpur (WT)	73.2	21.0	22.5	5.8
Makawanpur (CT)	87.5	37.5	0.0	0.0
Morang (ET)	78.1	46.9	0.0	0.0
Parsa (CT)	85.1	18.4	43.7	5.8
Rautahat (CT)	66.2	9.9	0.0	0.0
Sunsari (ET)	69.7	42.7	40.5	1.1

surveyed had experienced some elephant damage. In the past five years, over half (55%) of the households had experienced very high levels of conflict and another 26% had experienced a high frequency of conflict (Table 1). Binary logistic regression identified that with each increase in level of intensity of elephant damage (low, moderate, high to very high), the chances of house damage increased by 88% ($\chi^2 = 51.96$, $p < 0.0001$). Property damage was positively associated with the respondents' reported frequency of HEC whereas crop damage was not. Residents of ET experienced very high conflict more frequently (66%) than those of CT or WT (49% each)(Table 1). Most elephant damage occurred between September and December, with an additional peak occurring in July (Fig. 2).

Electric fencing (0.974) and economic benefits (0.954) have large positive loadings on factor 1 (Table 3), indicating factor 1 describes conservation measures in response to elephant encroachment or resulting from ecotourism. Crop damage (0.708) and property damage (0.797) have large positive loadings on factor 2 (Table 3), indicating factor 2 describes overall damage experienced as a result of elephant encroachment. High communality values (Table 3) indicate that variables were well represented by the two factors. The percentage variance indicates that 46.7% of the variability in the data was explained by factor 1, whereas both the factors (factor 1 and 2) together explained 75.9% of the variability in the data. Factor analysis confirmed our predictions that the percentages of the households experiencing crop and property damage in each district represented negative variables for residents' attitudes towards HEC, whereas the percentage of households with electric fencing facilities in the area, and households perceiving economic benefit from wildlife protection represented positive variables (Fig. 3). The score plot revealed that CT ranked high for fence installations and ecotourism benefits, whereas ET ranked high for crop and property damages (Fig. 3). Specifically, house damage for ET residents was at 43%, with less home damage occurring in WT (25%), and CT (17%) (Table 2).

Table 3. Rotated factor loading, communalities, and variance explained by the factors. Factor 1 describes the conservation measures whereas factor 2 describes the damage variables.

Variable	Factor 1	Factor 2	Communality
% crop damage	–0.077	0.708	0.507
% property damage	–0.069	0.797	0.640
% electric fencing	0.974	–0.017	0.948
% economic benefits	0.954	–0.178	0.942
Variance	1.869	1.169	3.038
% variance explained	0.467	0.292	0.759

Rates of HEC were reduced near national parks (Chitwan and Bardia National Parks), where a higher percentage of electric fences were located (Table 2). Moreover, people residing near national parks perceived better economic benefits resulting from wildlife conservation from ecotourism (Table 2). Higher house damage (2.58 times more) was observed in the districts that had both residential and mobile elephant herds ($\chi^2 = 38.18$, $p < 0.0001$) compared to those districts with only residential elephant herds. In contrast, there was no difference in the levels of crop damage by residential and mobile herds.

Among districts, a score plot from factor analysis also revealed that Makawanpur (CT), Jhapa (ET), Morang (ET) and Bardia (WT) ranked high in elephant damage, whereas Chitwan (CT) and Bardia (WT) ranked high on conservation measures. Similarly, Rautahat District (CT) ranked low for both factors (conservation measures and damage variables) (Fig. 3). Makawanpur District (CT) ranked highest for damage (Fig. 3), yet only one settlement from Makawanpur District was negatively affected from elephants, indicating a localized effect.

Human practices and HEC

Binary logistic regression demonstrates that only the number of crops grown on farms, growing of rice, and presence of large maize fields had statistically significant associations with crop damages ($\chi^2 = 64.72$, $p < 0.0001$). The frequency

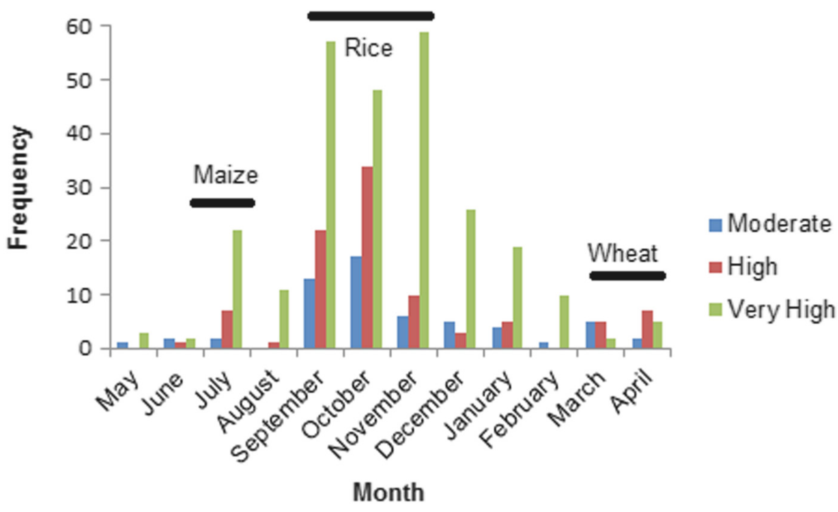

Figure 2. Month-wise HEC intensity in Nepal (2007–2012). Each month damages are presented in percentage of total damages. Traditional crops growing and harvesting seasons were shown by lines above the months.

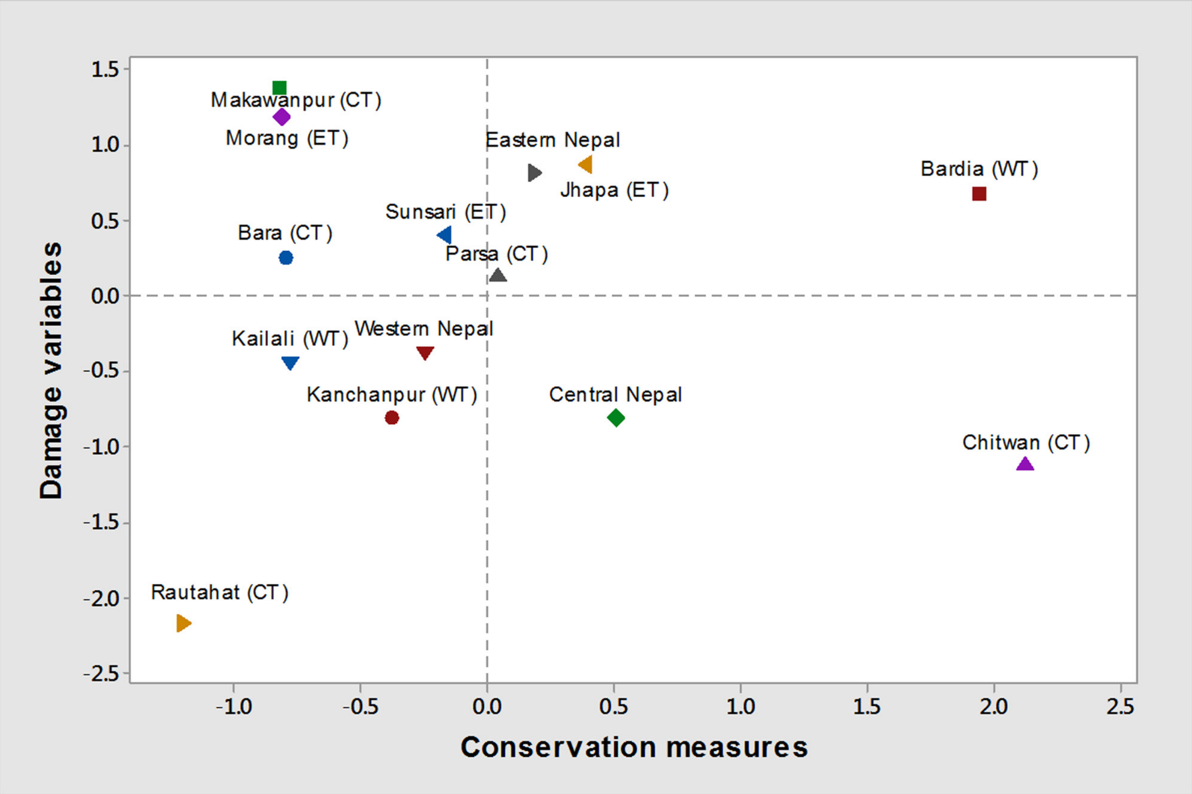

Figure 3. A score plot of the Terai districts of Nepal based on damage variables (crop damage and property damage) and conservation variables (electric fencing and economic benefit from ecotourism).

of crop raiding was increased with the number of crops grown on the farms by 1.36 times ($\chi^2 = 9.30$, $p = 0.002$). Those households which grew more than two traditional crops in a year had higher frequency of damage.

Most (92%) residents grew rice on their farms followed in frequency by maize and wheat. Fields having traditional crops such as rice and maize were targeted by elephants most frequently. The rice growing season begins in July and harvest starts in November, but the timing is variable according to which rice species is grown. Most conflict occurred during rice harvest (Fig. 2), and farmers of over two-thirds of rice fields had experienced crop damage. Cultivating rice increased the risk of elephant raid in the crop fields by 2.49 times ($\chi^2 = 11.54$, $p = 0.001$). Maize is usually harvested in June/July, whereas wheat is harvested in April. About half of the households growing maize were raided, whereas one-fifth of the wheat fields were raided. Large maize fields were most frequently targeted by elephants as indicated by a significant maize and farm size interaction ($\chi^2 = 4.46$, $p = 0.035$).

The growing of specific tree species around the home increased the chances of damage to houses by elephants. Stepwise binary logistic regression revealed that chances of house damage was significantly associated with bananas, bamboo, and alcohol production at home ($\chi^2 = 19.94$, $p = 0.001$). Half (54%) of the households raised bananas, of which one-third (33%) of those experienced house damage from elephants (Table 4). The frequency of home damage was increased when bananas were raised ($\chi^2 = 12.04$, $p = 0.001$). About 17% of the houses had bamboo trees in their home gardens, with one-fourth (23%) of those households experiencing house damage (Table 4). Bamboo significantly decreased the chance of house damage from elephants by 40% ($\chi^2 = 8.01$, $p = 0.002$). The incidence of house damage being initiated at the kitchen (26%) was greater than the surface area represented by those kitchens (~10%). In most cases, elephants knocked down the homes completely. One-fourth of the households produced alcohol at home for local consumption, with one-third (31%) of those households being attacked by elephants. Alcohol production increased the chances of elephant attack to the house ($\chi^2 = 3.97$, $p = 0.046$).

In contrast to the above, almost half (46%) of the households grew mangoes, with 30% of those households attacked and one-fifth (22%) of the households raised jackfruit around the home (Table 4) but both had no significant association with home damage. There was no change in house damage by elephants relative to the number of tree species grown around the home.

Table 4. Percentage of houses (property) damage relative to the types of fruit plants raised in home gardens.

Fruit tree	Total no. of houses having fruit trees	No. of houses damaged	% of the houses being raided
Jackfruit	256	73	28.5
Sugarcane	53	15	28.3
Bamboo*	201	47	23.4
Litchi	65	19	29.2
Mango	547	163	29.8
Banana*	634	209	33.0

*significant at $\alpha = 0.05$.

Discussion

Demographic effects and HEC

Human–elephant conflict (HEC) is frequent in the Terai of southern Nepal, with more than half of the households surveyed experiencing high frequencies of elephant damage. Our findings of the border regions of ET experiencing the greatest elephant damage are consistent with those identified by Neupane et al. (2014), where they tabulated published HEC incidents over a 10-year period; most reported damage was associated with trans-border mobile herds. Moreover, HEC has worsened in the past decade, resulting in increased casualties to both humans and elephants (Neupane et al. 2014). Lastly, this is a pervasive problem among Asian countries, as on-going HEC has been reported in India (Williams et al. 2001), Sri Lanka (Campos-Arceiz et al. 2009), and Indonesia (Hedges et al. 2005).

Farmers in rural Nepal are poor, and up to half of those affected by HEC do not grow enough food for their subsistence. Therefore, losing even a small portion of their production to elephants may be burdensome to the family. This burden would be most severe for residents of WT, as these households consist of subsistence farmers with small landholdings. The majority of the households surveyed throughout the Terai possessed medium sized farms (10–30 kattha) which were relied upon to fulfill family needs.

Trans-border movements of elephants are seasonal and are typified by large herds which tend to be more aggressive than the smaller-sized residential herds (Shrestha et al. 2007, Pradhan et al. 2011, Neupane et al. 2014). HEC was greatest during the winter, when rice matures, and showed a second peak during the harvest of maize in the summer. Similar to this study, other studies have identified peaks of damage from elephants coinciding with crop ripening and harvesting in India (Sukumar 1990) and in Sri Lanka (Campos-Arceiz et al. 2009). This seasonal difference in magnitude of crop and property damage by elephants may reflect low natural food availability during the winter rather than a preference of elephants of rice versus maize. For example, African elephants showed a preference for maize among crops grown (Barnes et al. 2005, Chiyo et al. 2005). Energy-rich farm crops may supplement elephant diets during these periods of low food availability (Rood et al. 2010). Thus, one possible mitigation measure may be the augmentation of elephant habitat with natural cool weather crops during these winter periods. Similarly, Putman and Staines (2004) found that supplementing winter feeding for wild red deer *Cervus* spp. in Europe and North America was effective to achieve conservation aims.

Residents adjacent to national parks were more favorable to elephant conservation in our study. National parks such as Chitwan National Park (CT) and Bardia National Park (WT) may affect HEC in two important ways: 1) there is often better electric fencing around the villages surrounding national parks, which helps to reduce HEC; and 2) ecotourism from national parks provides an increase in economic benefit to local residents. These improvements may enhance the residents' tolerance of HEC, as park authorities of these forests have better management programs to reduce wildlife movement into human settlements and maintain funds for local development available to local residents (Neupane 2007, Paudel et al. 2007). In contrast, factor analysis revealed that highly impacted Jhapa and Morang districts (ET) were not adjacent to national parks, and therefore ecotourism benefits were low. Further, residents of those districts experienced extensive damage from mobile herds of elephants crossing the border with India (Shrestha et al. 2007, Pradhan et al. 2011, Neupane et al. 2014).

Neupane et al. (2017) surveyed the attitudes of residents towards HEC mitigation, and found a negative relationship between the degree of damage from elephants and residents' willingness to pay for HEC mitigation in the Terai. Variables Neupane et al. (2017) identified to be positively impacting residents' willingness to pay towards HEC mitigation were residents' education levels, income, and the extent and frequency of human injury and death. Conversely, factor analysis in the present study revealed that Chitwan and Bardia districts scored high on benefits with moderate damages from elephants. These areas have comparatively better fencing and ecotourism is perceived by residents as a benefit to the local economy.

Home-use practices and property damage

Elephants preferentially attack homes which produce alcohol. Thus, alcohol production should be moved away from the house to reduce elephant damage. Consistent with anecdotal statements, elephants that are assumed to be in search of food preferentially attack the kitchens when first impacting houses; kitchens are usually adjacent to both the production of alcohol and the storage of grains following harvest.

Gardening practices adjacent to the home also influence elephant damage. Having fruit trees such as bananas in near proximity to the home increased the chances of elephants damaging houses. Although households growing mango trees had a non-significant increased incidence of elephant damage, households growing mangoes typically also grew bananas which increased risk of house damage. Consistent with our findings, banana trees have been shown to be a preferred target by both Asian (Sukumar 1990) and African elephants (Lahm 1994, Barnes et al. 2005). Thus, a second potential mitigation effort would be the use of and placement of fenced community orchards at the edges of settlements rather than adjacent to individual houses. In contrast, households growing bamboo, which tends to be grown further away from the home than fruit trees, had a reduced frequency in elephant damage, consistent with the results of Kumar et al. (2004) in India. Although elephants will readily feed on bamboo (Kumar et al. 2004), bamboo may act as a buffer since elephants will feed on bamboo distant from houses.

Conclusions and recommendations

Patterns of elephant raiding are often land-use and home-activity specific, and hence mitigation strategies should be targeted in that direction. A mitigation plan can only be implemented effectively after examining the conflict patterns and establishing their connections to anthropogenic activities (Sitati et al. 2003, Jackson et al. 2008). For example, a single male elephant is more probable to cause property damage whereas herds of elephants are involved in crop damage (Shrestha et al. 2007, Neupane unpubl.). Land-use planning can provide a long term approach to mitigate human–wildlife conflict, as that planning accommodates both humans and wildlife (WWF 2005). However, HEC patterns relative to land-use practices are rarely studied. Creating a buffer zone at the boundaries of human settlements and forests would provide time for residents to detect wildlife intrusion and thus provide time for the deterrence of large mammals such as elephants (Chardonnet et al. 2010). Being inexpensive and rapid growing, bamboo trees could therefore be positioned as living fence rows around the perimeters of settlements to reduce HEC.

In Nepal, current practices dealing with HEC are often reactionary at the time of elephant encroachment, including the use of fire and fire crackers as repellents. Other methods presently employed for mitigating HEC require substantial infrastructure investment such as electric fencing, trenches, and watch towers (Shrestha et al. 2007). The use of electric fencing represents an expensive initial investment and regular maintenance. An early-warning siren system could be effective to alert and prepare residents to defend against elephant intrusions. Additionally, corridor management between forests and the enhancement of protected forests are other measures that could help to control HEC regionally (Neupane et al. 2017). However, the major problem of implementing these measures is the lack of financial resources of residents in the impacted regions, as the government has not invested sufficient funds to initiate better measures. Neupane et al. (2017) have identified the potential financial resources that could be collected from local residents if the mitigation and compensation programs are improved. Our results suggest that careful planning for home- and land-use patterns may reduce HEC. For example, simple cost-effective measures such as the planting of bamboo and fruit trees away from homes would likely provide beneficial results. Further, planting fruit trees or other cool weather crops inside forests could also reduce the elephant encroachment to villages.

The growing of alternative crops adjacent to forests could be effective in mitigating HEC, yet represents a fundamental shift in local agricultural practices, as both rice and maize are dietary staples of the region. Several crops have been proposed which are unfavorable to elephants such as tea, tobacco and chili (Nelson et al. 2003). In Africa, Parker and Osborn (2006) suggested the planting of chili, and Aharikundira and Tweheyo (2011) recommended the planting of tea plantations to serve as buffer crops against raiding elephants. However, the growing of perennial alternative crops such as tea represents an initial cash-negative investment as these crops require years to mature and generate a profit (Mitra 1991). Locally, in the buffer zone of Bardia National Park, a mentha plantation was developed to control wildlife encroachment from the forest, especially one-horned rhinos *Rhinoceros unicornis* (DNPWC 2009); megafauna rarely feeds on mentha (Thapa 2010).

Barriers to the implementation of the strategies above include a lack of time and money for local residents. Households in the rural villages are poor; alternative cropping other than rice and maize could be pursued only with government or NGO subsidies. Markets must be explored and transport mechanisms must be developed as these alternative crops must be economically viable to replace the income and food provided by traditional crops such as rice and maize.

Ours is the first study to systematically describe the association of HEC with land- and home-use practices in Nepal, and to the best of our knowledge the first study to address these questions in south Asia. As elephants learn to foil HEC mitigation practices quickly, it has been recommended to use a variety of HEC mitigation techniques (Gunn et al. 2014). Our results point toward novel HEC mitigation techniques that add to the variety of techniques available to local wildlife managers.

Acknowledgements – We would like to thank all field assistants for their help to conduct the survey for this study. We are appreciative of assistance and advice regarding our HEC studies from various park officials especially Mr. Kamal Jung Kunwar, Mr. Tika Ram Adhikari and Mr. Yuvraj Regmi.
Funding – This work was funded by several agencies including the US Fish and Wildlife Service, Arkansas State University, and the Mohammad bin Zayad Species Conservation Fund.
Conflict of interest – We declare that we have no conflict of interest.

References

Aharikundira, M. and Tweheyo, M. 2011. Human-wildlife conflict and its implication for conservation around Bwindi Impenetrable National Park. – In: Watson, A. et al. (eds), Science and stewardship to protect and sustain wilderness values. 9th World Wilderness Congr. Symp., November 2009. USDA Forest Service Proceedings RMRS-P-64, pp. 39–44.

Bajimaya, S. 2012. Managing human-wildlife conflict in Nepal. – In: Acharya, K. P. and Dhakal, M. (eds), Biodiversity conservation in Nepal: a success story. Dept of National Parks and Wildlife Conservation, Kathmandu, Nepal, pp. 31–44.

Barnes, R. F. W. et al. 2005. Risk of crop raiding by elephants around the Kakum Conservation Area, Ghana. – Pachyderm 39: 19–25.

Campos-Arceiz, A. et al. 2009. The human–elephant conflict in southern Sri Lanka: type of damage, seasonal patterns, and sexual differences in the raiding behavior of elephants. – Gajah 31: 5–14.

CBS (Central Bureau of Statistics) 2014. Population monograph of Nepal. Vol. III (economic demography). – Government of Nepal, National Planning Commission Secretariat, Kathmandu, Nepal.

Chardonnet, P. et al. 2010. Managing the conflicts between people and lion: review and insights from the literature and field experience. – Wildl. Manage. Working Paper 13. FAO of the UN, Rome.

Chiyo, P. I. et al. 2005. Temporal patterns of crop raiding by elephants: a response to changes in forage quality or crop availability? – Afr. J. Ecol. 43: 48–55.

Choudhury, A. et al. 2008. *Elephas maximus*. – In: IUCN 2011. IUCN Red List of Threatened Species. Ver. 2011.1. <www.iucnredlist.org> accessed 12 July 2011.

Cordingley, M. 2008. Participatory development in Nepal: challenges and opportunities for conservation in managing human-elephant conflict. – Gajah 29: 41–44.

DNPWC (Department of National Parks and Wildlife Conservation 2008. The elephant conservation action plan for Nepal. Report. – Dept of National Parks and Wildlife Conservation, Kathmandu, Nepal.

DNPWC (Department of National Parks and Wildlife Conservation) 2009. The status and distribution of the greater

one-horned rhino in Nepal. Report. – Dept of National Parks and Wildlife Conservation, Kathmandu, Nepal.
Distefano E. 2005. Human–wildlife conflict worldwide: collection of case studies, analysis of management strategies and good practices. – Report. FAO, Rome.
Gunn, J. et al. 2014. The influence of lunar cycles on crop raiding elephants; evidence for risk avoidance. – Afr. J. Ecol. 52: 129–137.
Hair, J. F. et al. 2009. Multivariate data analysis, 7th edn. – Prentice Hall.
Hedges, S. et al. 2005. Distribution, status, and conservation of Asian elephants (*Elephas maximus*) in Lampung Province, Sumatra, Indonesia. – Biol. Conserv. 124: 35–48.
Hoare, R. E. 1999. Determinants of human–elephant conflict in a land-use mosaic. – J. Appl. Ecol. 36: 689–700.
Hosmer, D. W. and Lemeshow, S. 2000. Applied logistic regression. – Wiley.
Jackson, T. P. et al. 2008. Solutions for elephant *Loxodonta africana* crop raiding in northern Botswana: moving away from symptomatic approaches. – Oryx 42: 83–91.
Khounboline, K. 2007. Human–elephant conflict (HEC) pilot study in southern Lao PDR. – Gajah 26: 18–20.
Kumar, M. A. et al. 2004. The elephant hills: conservation of wild Asian elephants in a landscape of fragmented rainforests and plantations in the Anamalais, India. – CERC Tech. Rep.t No. 10. Nature Conservation Foundation, Mysore, India.
Lahm, S. A. 1994. Impact of elephants on agriculture in Gabon. African Elephant Conservation Programme Final Report. – European Commission DGVIII Ecology in Developing Countries Programme – The Environment and Development Group, Oxford.
Lahm, S. A. 1996. A nationwide survey of crop raiding by elephants and other species in Gabon. – Pachyderm 21: 69–77.
Messmer, T. A. 2009. Human–wildlife conflicts: emerging challenges and opportunities. – Human–Wildlife Conflicts 3: 10–17.
Mitra, N. 1991. Indian tea industry: problems and policies. – Econ. Political Weekly 26: 153–156.
Musyoki, C. 2014. Crop defense and coping strategies: wildlife raids in Mahiga 'B' village in Nyeri District, Kenya. – Afr. Study Monogr. 35: 19–40.
Nelson, A. et al. 2003. A review of human–elephant conflict management strategies. – Wildl. Conserv. Res. Unit, Oxford Univ.
Neupane, D. 2007. Climate change, protected areas, and biogas. – Habitat Himalaya fact file no. 14. Resources Himalaya Foundation, Kathmandu, Nepal.
Neupane, D. et al. 2014. Temporal and spatial patterns of human–elephant conflict in Nepal. – In: 2013 International Elephant & Rhino Conserv. Res. Symp. Proc, August 2013, Pittsburgh Zoo and PPG Aquarium, pp. 856–888.
Neupane, D. et al. 2017. Willingness to pay for mitigating human-elephant conflict by residents of Nepal. – J. Nat. Conserv. 36: 65–76.
Paudel, N. S. et al. 2007. Buffer zones: new frontiers for participatory conservation? – J. For. Livelihood 6: 44–53.
Perera, B. M. A. O. 2009. The human–elephant conflict: a review of current status and mitigation methods. – Gajah 30: 41–52.
Parker, G. E. and Osborn, F. V. 2006. Investigating the potential for chilli *Capsicus spp.* to reduce human–wildlife conflict in Zimbabwe. – Oryx 40: 343–346.
Peeters, B. et al. 2012. Improved process control of an industrial sludge centrifuge-dryer installation through binary logistic regression modeling of the fouling issues. – J. Process Control 22: 1387–1396.
Pradhan, N. M. B. et al. 2011. Current status of Asian elephants in Nepal. – Gajah 35: 87–92.
Putman, R. J. and Staines, B. W. 2004. Supplementary winter feeding of wild red deer *Cervus elaphus* in Europe and North America: justifications, feeding practice and effectiveness. – Mammal Rev. 34: 285–306.
Riitters, K. H. et al. 1995. A factor analysis of landscape pattern and structure metrices. – Landscape Ecol. 10: 23–39.
Rood, E. et al. 2010. Using presence-only modeling to predict Asian elephant habitat use in a tropical forest landscape: implication for conservation. – Divers. Distrib. 16: 975–984.
Shrestha, R. et al. 2007. A case study on human–wildlife conflict in Nepal – with particular reference to human–elephant conflict in eastern and western Terai regions. – Report. Species Program, WWF International, Switzerland.
Sibanda, W. and Pretorius, P. 2012. Comparative study of the application of Box–Behnken design (BBD) and binary logistic regression (BLR) to study the effect of demographic characteristics on HIV risk in South Africa. – J. Appl. Med. Sci. 1: 15–40.
Sitati, N. W. et al. 2003. Predicting spatial aspects of human–elephant conflict. – J. Appl. Ecol. 40: 667–677.
Sukumar, R. 1990. Ecology of the Asian elephant in southern India. II. Feeding habits and crop raiding patterns. – J. Trop. Ecol. 6: 33–53.
Thapa, S. 2010. Effectiveness of crop protection methods against wildlife damage: a case study of two villages at Bardia National Park, Nepal. – Crop Protection 29: 1297–1304.
Velde, P. F. 1997. A status report of Nepal's wild elephant population. – Report. WWF International, Switzerland.
Vijayan, S. and Pati, B. P. 2002. Impact of changing cropping patterns on man–animal conflicts around Gir protected area with specific reference to Talala sub-district, Gujarat, India. – Popul. Environ. 23: 541–559.
Williams, A. C. et al. 2001. Elephant–human conflicts in Rajaji National Park, northwestern India. – Wildl. Soc. Bull. 29: 1097–1104.
WWF 2005. Human–wildlife conflict manual. – Wildlife management series. Harare, Zimbabwe, World Wide Fund for Nature Southern African Regional Programme Office.
Yonzon, P. 2008. Elephants on the run. – Habitat Himalaya fact file no. 15. Resources Himalaya Foundation, Kathmandu, Nepal.