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Can forest fragmentation and configuration work as indicators of human–wildlife conflict? Evidences from human death and injury by wildlife attacks in Nepal

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ABSTRACT

Fragmented forests and heterogeneous landscapes are likely to have less natural vegetation and smaller core areas, a low degree of landscape connectivity, high prevalence of anthropogenic edges, and high landscape heterogeneity, which may alter—at varying degrees—behavior of wildlife species such as attacks on humans. We evaluated whether or not forest fragmentation (e.g. shape, size and distribution of forest patches measured as landscape shape index, effective mesh size, and landscape heterogeneity), habitats (proportion of bush and grassland, distance to water sources), and human disturbances (human population density) have a significant relationship with frequencies of human deaths and injuries by Bengal tiger (*Panthera tigris tigris*), common leopard (*Panthera pardus*), one-horned rhinoceros (*Rhinoceros unicornis*) and Asiatic elephant (*Elephas maximus*). Data on human injury and death were obtained from a national survey over five years (2010–2014). The relationship between wildlife attacks and landscape attributes were investigated using a zero-inflated Poisson regression model. Attacks by tigers were significantly and positively associated with forest fragmentation (effective mesh size which is high in a landscape consisting of disconnected small patches). Attacks by common leopards were strongly positively related with landscape heterogeneity, and negatively related to the proportion of bush and grassland. Attacks by one-horned rhinoceros were positively significantly related to the distance to water sources, and proportion of bush and grassland in the landscape. Attacks by elephants were strongly and positively associated with the forest fragmentation (landscape shape index, which increases as patches in the landscapes becomes disaggregated). These results suggest that forest fragmentation is inevitably a critical driver of human–wildlife conflicts, although the extent of effects varies depending on species specific habitat requirements.

1. Introduction

Large mammals play important roles in the forest ecosystems mostly by maintaining prey populations and seed dispersal (Berger et al., 2001; Tanner, 1975). They are regarded as keystone species of ecosystems (Caro, 2010; Roberge and Angelstam, 2004; Williams et al., 2000). Forest fragmentation and deforestation lead to loss of core forest areas, disruption of dispersal ability of wildlife in their home ranges, and deterioration of quality habitats by different means such as frequent forest fire and invasion by alien flora and fauna, etc. (Bennett, 1990; Laurance et al., 2000; Lehmkuhl and Ruggiero, 1991). Furthermore, forest loss and degradation bring wildlife into human proximity and cause confrontation because both wildlife and humans compete for shared resources (Distefano, 2015; Woodroffe et al., 2005). Consequently, wildlife raid crops, damage property and kill humans. The subsequent aggressive actions by humans result in further escalation of conflict, including retaliatory killings of wildlife (Distefano, 2015; Michalski et al., 2006; Woodroffe et al., 2005).

Bengal tiger *Panthera tigris tigris* (Linnaeus, 1758), common leopard *Panthera pardus fusca* (Meyer, 1974), Asiatic one-horned rhinoceros *Rhinoceros unicornis* (Linnaeus, 1758) and Asiatic elephant *Elephas maximus* (Linnaeus, 1758) are top ranked conflict animals in Nepal in

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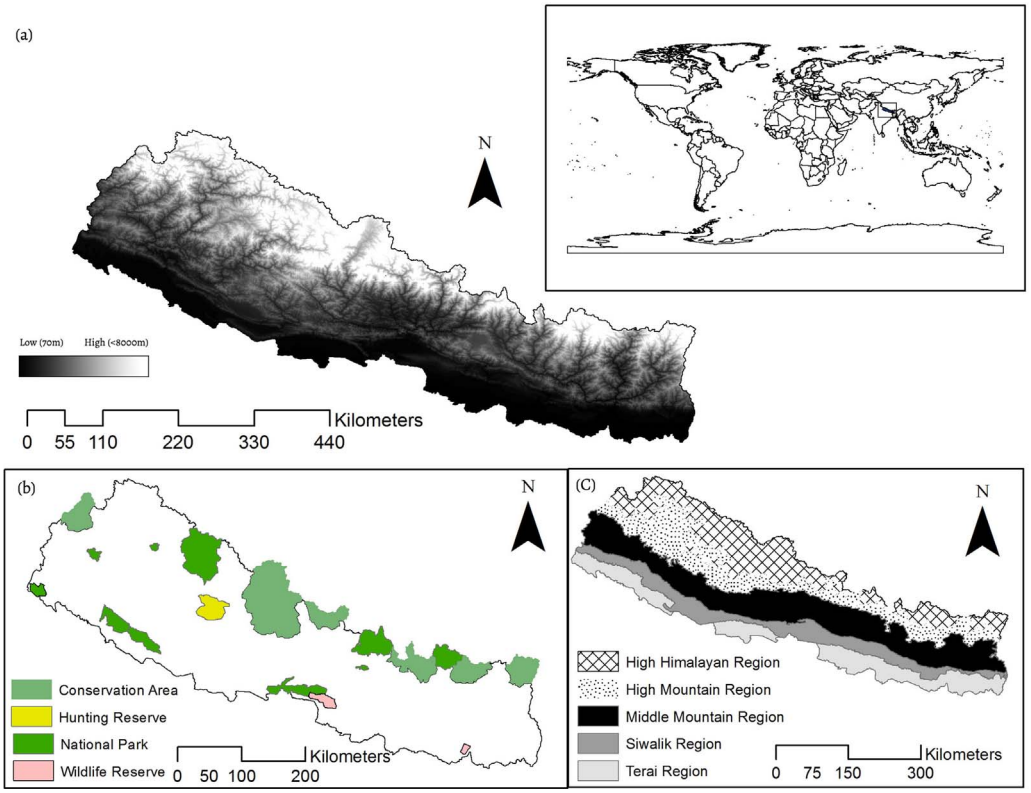

Fig. 1. Mountain landscapes of Nepal: (a) altitudinal gradient of Nepal, (b) protected areas of Nepal, and (c) physiographic division of Nepal (LRMP, 1986).

terms of fatalities and injuries of humans (Acharya et al., 2016). The first three, considered globally threatened mega-fauna, are now mostly restricted to a few protected areas of lowland Nepal and their adjoining forests due to rapid conversion of forests to agricultural lands and their fragmentation (Jnawali et al., 2011; Primack et al., 2013). Common leopards are widely distributed from the lowland to the midhills (Jnawali et al., 2011). The midhills forests have endured a long history of human influence as early settlers occupied these areas (Hagen, 1973). Both midhills and lowland forest are now fragmented forest in the human dominated landscape. As a result, human–wildlife conflict is common throughout Nepal (Acharya et al., 2016; Bhattarai and Fischer, 2014; Gurung et al., 2008; Jnawali, 1989; Pandey et al., 2015; Pant et al., 2015). The major types of conflict include death and injury of humans, crop damages, livestock depredation, property damage and retaliatory killing of wildlife and damages to their habitats. Conflict mitigation approaches include many traditional and new methods such as providing monetary compensation to victims (e.g. crop and livestock insurance schemes), construction of electric fences and trenches along forest borders to limit wildlife movement, and construction of predator-free corrals to minimize attacks on livestock (Acharya et al., 2016). Although these measures are critically important to mitigate conflict for the short term, there is a need for consideration of the long-term ecological requirements of the species in question (Distefano, 2015; Gore et al., 2008; Michalski et al., 2006; Treves et al., 2004).

Current strategies for biodiversity conservation in Nepal prioritize restoration of forested landscapes, with a particular emphasis on ecological corridors between protected areas, and reestablishment of connectivity along an attitudinal gradient of mountain landscapes (MFSC, 2010; MOFSC, 2015). Human–wildlife conflict is increasing in both frequency and severity throughout the country. Most of the studies on human–wildlife conflict are focused on quantifying the damage and species involved in the conflict. Few studies have been conducted to determine if, and to what extent, landscape fragmentation induces human–wildlife conflict, and whether habitat requirements outweigh the effects of fragmentation (Michalski et al., 2006; Treves et al., 2006).

Our ultimate goal was to evaluate the influence of forest fragmentation, human disturbance and landscape heterogeneity on conflict events, and determine whether forest fragmentation is a better explanatory variable than the others. We used data on the locations of conflicts associated with Bengal tiger, Asiatic one-horned rhinoceros, and Asiatic elephant collected between January 2011 and December 2014 to examine species specific responses to forest fragmentation (landscape shape index, effective mesh size and landscape heterogeneity). This assessment includes proportion of bush and grassland, distance to water sources, and human population density. Landscape shape index measures edges of forest patches and their aggregation, whereas effective mesh size measures probability that two randomly chosen pixels are not in the same patches, and thus characterizes subdivision of a landscape independently of its size. Landscape heterogeneity is defined by Shannon's diversity index which measures abundances of habitat types (McGarigal et al., 2002). Proportion of bush and grassland measures ratio of landscape occupied by bush and grassland. Distance to water sources measures shortest Euclidean distance between each pixel to its nearest water sources. Human population density measures numbers of people per unit area. We use our results to advise conservation planning in Nepal.

2. Material and methods

2.1. Study area

Nepal is disproportionately rich in biodiversity in terms of its surface area, mainly due to great variation in altitude (70–8848 m), precipitation, temperature and physiographic divisions (Paudel et al., 2012; Primack et al., 2013). The physiographic divisions of country include: (1) Tarai (flat land), (2) Siwaliks (the youngest Himalayan range composed of sedimentary rock and boulders), (3) middle mountain (a mountain range and intervening landscapes between 1500 m and 3000 m asl), (4) high mountain, and (5) high Himalaya (Fig. 1). The country's biodiversity is recognized for its high species