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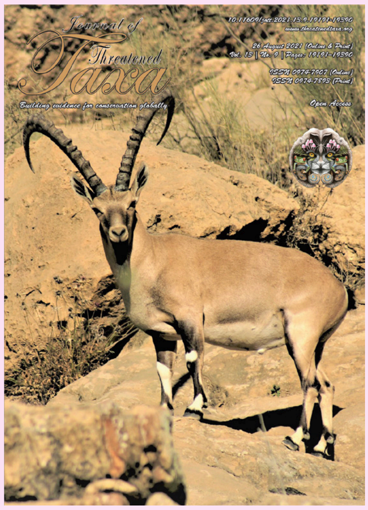

**Article**

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ARTICLE

# On the impact of earthquake-induced landslides on Red Panda *Ailurus fulgens* (Mammalia: Carnivora: Ailuridae) habitat in Langtang National Park, Nepal

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**Abstract:** In addition to the threats of human encroachment, infrastructure development, tourism activities, habitat fragmentation, and human-wildlife interactions, natural disasters also pose a threat to the habitat of endangered species such as the Red Panda. This study aims to assess the impact of the 2015 Gorkha earthquake-induced landslides on the Red Panda's habitat in Langtang National Park (LNP), central Nepal Himalaya. Remote sensing and geographical information system were applied to estimate the potential and core habitats of the Red Panda, and collect information on earthquake-induced landslides. Field sampling and verification of remotely collected data were done within a year of the earthquake. Considering preferred vegetation types, elevation range, aspects, distance from water sources, and Red Panda presence points, an area of 214.34 $km^2$ was estimated as the potential habitat of Red Panda in the Park. Thirty-nine landslides were identified in LNP triggered by the Gorkha earthquake, 14 of which occurred in the core Red Panda habitat. As a result of the earthquake-induced landslides, a significant decrease in tree density was observed in the areas affected by the landslides. Similarly, the bamboo cover was observed to be significantly lower in the areas affected by landslides compared to the unaffected adjacent areas. The average size of the landslide, causing damage to the Red Panda habitat was 0.8 ha. The potential habitat damaged by the earthquake-induced landslide was estimated to be 11.20 ha which is equivalent to the habitat required by one Red Panda. The findings could be useful in initiating restoration of the damaged Red Panda habitat in LNP.

**Keywords:** Disaster, endangered species, geographical information system, habitat loss, habre, natural hazards, threat, wildlife.

**Nepali:** वन्यजन्तुहरुको बासस्थान अतिक्रमण, पूर्वाधार विकास, पर्यटनका गतिविधिहरु, बासस्थान विखन्डन, र मानव वन्यजन्तु द्वन्दका अतिरिक्त, प्राकृतिक प्रकोपले पनि अस्तित्वको खतराको सूचीमा रहेका रेड पाण्डा (हाब्रे) जस्ता प्रजातिहरुको बासस्थानमा जोखिम पैदा गर्दछ। यो अध्ययनको मुख्य उदेश्य गोरखा भूकम्पबाट सृजित भूस्खलनहरुले नेपालको लाङटाङ राष्ट्रिय निकुञ्ज भित्र रेड पाण्डाको बासस्थानमा पारेको प्रभावको पहिचान तथा आँकलन गर्नु हो। यसका लागि रिमोट सेन्सीन्ङ्ग र भौगोलिक सूचना प्रणाली, स्थलगत अध्ययन तथा अवलोकन, नमुना भूस्खलन (पहिरो) हरुको विस्तृत तथ्याङ्क संकलन जस्ता विधीहरु अपनाईएको थियो। यस अध्ययन अनुसार लाङटाङ राष्ट्रिय निकुञ्जमा रेड पाण्डाको सम्भावित बासस्थान २१४.३४ वर्ग कि.मि. क्षेत्रफलमा फैलिएको छ। निकुञ्ज भित्र पहिचान गरिएका ३९ पहिरो मध्ये १४ वटा पहिरो रेड पाण्डाको बासस्थानमा परेको देखिन्छ। भूस्खलन तथा पहिरोबाट रेड पाण्डाको लागि उपयुक्त भूगोल, खाद्य वनस्पति, बासस्थानका लागि रेड पाण्डाले रुचाउने रुख प्रजातिहरु र पानीको स्रोतमा प्रभाव परेको देखिन्छ। भूकम्पबाट सृजित भूस्खलनले लाङटाङ राष्ट्रिय निकुञ्ज भित्र करिब ११.२० हेक्टर रेड पाण्डाको सम्भावित बासस्थानलाई क्षति पुर्याएको अनुमान गरिएको छ। यस अध्ययनले भूकम्प जस्ता प्राकृतिक प्रकोपबाट मानवजाति मात्र हैन, वन्यजन्तु तथा तिनका बासस्थान समेत उत्तिकै जोखिममा रहने देखाउँछ।

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## INTRODUCTION

Natural disasters such as earthquakes can severely affect the earth's biodiversity. Some disasters may severely threaten plant and animal species due to the destruction of resources than the other ones (Lai et al. 2007; Ding & Miao 2015). The Gorkha earthquake (Mw 7.8), that hit Nepal on 25 April 2015, had triggered 4,312 co-seismic and post-seismic landslides (Kargel et al. 2016). The Gorkha earthquake had severely impacted forests and biodiversity, mainly by the earthquake-induced landslides (MOSTE 2015). Furthermore, the debris avalanche and the air blasts that were triggered by the earthquake flattened the forests up to 1 km (Collins & Jibson 2015). A loss of around USD 303 million was estimated in the environment and forestry sector due to the Gorkha earthquake (NPC 2015a,b).

Habitat loss due to fragmentation and degradation affects over 2,000 mammal species, which is considered as the greatest threat to biodiversity globally (Wang et al. 2014). Some 13,800 km$^2$ of suitable habitats are available for Red Pandas in Nepal (Panthi et al. 2019), which is significantly lower than the previous estimates by Kandel et al. (2015) and Thapa et al. (2018), who had estimated 17,400 km$^2$ and 20,150 km$^2$ of suitable habitat for Red Pandas, respectively. According to Yonzon et al. (1991) and Yonzon & Hunter (1991a) an area ranging 68–108 km$^2$ habitat within the Langtang National Park is suitable for Red Pandas; they are sensitive to even the slightest alteration in land use patterns; and 24–68 individuals were estimated in LNP residing in three to four population patches.

Increasing human population and interference to nature such as road construction and tourism activities are causing habitat destruction of Red Panda (Dorji et al. 2012). Furthermore, habitat fragmentation (Mahato & Karki 2005; Preece 2010; Wei & Zhang 2010), habitat loss (Wei et al. 1999a; Preece 2010), poaching (Choudhury 2001; Zhang et al. 2008; Sharma & Belant 2009; Zhou et al. 2013) and livestock grazing (Yonzon & Hunter 1991b; Mahato & Karki 2005; Sharma & Belant 2009; Dorji et al. 2012; Zhou et al. 2013) are also threatening Red Pandas seriously. Large-scale habitat loss and fragmentation are hampering gene flow among the Red Panda population (Hu et al. 2011). On the other hand, the majority of the subpopulations currently existing are of a smaller size, increasing the probability of their extinction, even in the absence of threats from humans (Jnawali et al. 2010). Studies have shown that Red Panda being bamboo specialists, more than 80% of their diets consist of bamboo grass and is a major habitat component (Reid et al. 1991; Wei et al. 1999b; Panthi et al. 2015; Bista et al. 2019). The survival of Red Pandas is also being threatened by deforestation and degradation caused by the collection of forest products (Mahato & Karki 2005; Bearer et al. 2007; Dorji et al. 2012; Zhou et al. 2013), killing by the locals (Mahato & Karki 2005), cattle herders, and domestic dogs (Yonzon & Hunter 1991a; Dorji et al. 2012).

In addition to the human-induced threat, natural disasters also pose significant threats to the survival of Red Panda (Deng et al. 2010; Zhang et al. 2011, 2012; Meng et al. 2016; Wang et al. 2018). Gorkha earthquake-induced landslides in the LNP have affected the habitat of the Red Panda. However, a systematic and scientific study on the extent of the impact has been lacking. Ecological considerations are crucial in disaster preparedness and post-disaster management (Chang et al. 2006). An earthquake-induced landslide would be one of the indicators to estimate impacts of the earthquake on important ecological parameters like habitat area, tree density and food preferred by Red Panda. This study aims to assess the impact of the Gorkha earthquake-induced landslide on the habitat of Red Panda in the LNP. Specifically, this study explores the effect of earthquake-induced landslides on vegetation preferred by Red Pandas as shelter and food (mainly bamboo) and estimate the loss of habitat.

## MATERIALS AND METHODS

### Study area

This study was carried out in the LNP (between 28.3856–27.9628 latitude and 85.2154–85.8849 longitude, IUCN category II, National Park). Established in 1976, LNP is one of the prime habitats of Red Panda in Nepal. It has an area of 1,710km$^2$ and extends over Nuwakot, Rasuwa, and Sindhupalchok districts of Nepal and is linked with the Qomolangma National Nature Preserve in Tibet to the North (DNPWC 2017) (Figure 1). Main Central Thrust (MCT) is one of the most tectonically significant structures in the Himalayan orogeny that extend across the LNP in the middle (Reddy et al. 1993). Another major Himalayan fault called Main Boundary Thrust (MBT) extends further south of the Langtang making the region seismically more vulnerable (Macfarlane et al. 1992). The region lies about 74.3 km away from the epicentre of the Gorkha earthquake. Multhala area, one of the core habitats of Red Panda in the park was considered for field sampling and survey. The sampled habitat has an area of 4.26 km$^2$. The field

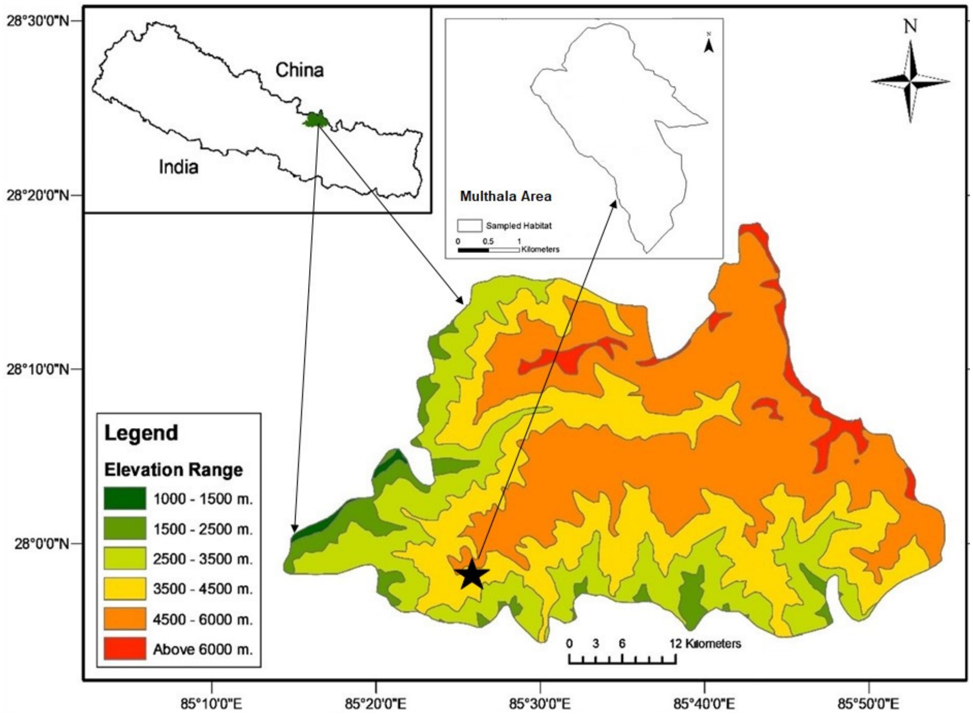


Figure 1. Location of Langtang National Park.

survey was conducted within one year of the Gorkha earthquake (22–29 March 2016).

## Data and methods

Primary data were collected from the field sampling, whereas other necessary data were collected from several secondary sources and open-access database (Table 1). Data on (i) Red Panda presence point (Kandel et al. 2015), (ii) rapid damage maps (Yun et al. 2015), (iii) earthquake-induced landslides points (Kargel et al. 2016), (iv) epicentres of Gorkha earthquake and aftershocks (Adhikari et al. 2015), (v) land cover map of Nepal, 2010 (Uddin et al. 2015), (vi) administrative boundary maps, and (vii) 30m Resolution Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) (Jha 2018) were collected.

Based on the literature on the niche and core habitat of Red Panda in LNP (e.g., Yonzon & Hunter 1991a; Yonzon et al. 1991; Kandel et al. 2015), we developed a potential habitat map of Red Panda in LNP for which we selected a maximum range for each niche factors. Broadleaved open/closed forests, needle-leaved open/closed forests were extracted from the land cover map of Nepal (Uddin et al. 2015). Although, sightings from lower elevations have also been recorded (e.g., at 2,210 m in Ilam, eastern Nepal; Bista et al. 2013), we used the elevation range of 2,800–3,900 m considering the sighting ranges of Red Panda in LNP. Preferred aspects (West, north, north-east, north-west) were extracted from the aspect map prepared out of the DEM using a surface analysis tool in GIS. The buffer map of less than or equal to 200 m from the water sources and geographical location of Red Panda signs in LNP were generated and used to develop the potential habitat map using QGIS version 3.0.3. The methodological flow chart is given in Figure 2.

Earthquake-induced landslides were masked for LNP from Kargel et al. (2016) and superimposed on the potential habitat map of Red Panda. Later, the validation of the landslides was done during the field visit. Based on the occurrence of landslides over the potential habitat, Multhala—one of the core habitats with high densities of signs and evidence of Red Panda—was selected for the field survey and sampling (Image 1a,b). The area was surveyed for the earthquake impact on the Red Panda habitat. Horizontal transect walk (n= 5) of length each 1,000 m was done along the five altitudinal belts at 2,900 m, 3,100 m, 3,300 m, 3500 m, and 3,700 m. Transect survey was carried out along small forest trails as opportunistic sightings of species is the most common data collection technique for the elusive Red Panda (Pradhan et al. 2001; Jnawali et al. 2010). Earthquake damage evidence along five horizontal transects were visually observed and recorded. Droppings of Red

Table 1. Description of data and sources.

| Data | Source | Description |
|---|---|---|
| Red Panda presence point | Kandel et al. 2015 | Freely available Red Panda presence points were extracted and overlaid in LNP on the map. |
| Rapid damage maps | Yun et al. 2015 | Information of earthquake-induced landslides taken from this part of the literature helped to identify the areas of occurence of landslides in core habitat. |
| Earthquake-induced landslides points | Kargel et al. 2016 | Earthquake-induced landslides points were overlaid in LNP in the map which helped for accuracy and validation of rapid damage images. |
| Epicentres of Gorkha earthquake and aftershocks | Adhikari et al. 2015 | Epicentres of the Gorkha earthquake and aftershocks overlaid in the map of LNP. |
| Land cover map of Nepal, 2010 | Uddin et al. 2015 | The land cover map was overlaid in the map of LNP to select the range of preferred vegetation to map out a potential habitat range within LNP. |
| Digital Elevation Model (SRTM 30 m) | USGS 2017 | 30m Resolution Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) was extracted from United States Geological Society (https://earthexplorer.usgs.gov) |
| Landslides points and dimensions | Transect Walk | Landslides were observed along transects in the sampling area and the dimensions were measured. |
| Tree density, vegetation cover and canopy cover of bamboo | Quadrat sampling | Quadrats of 10 x 10 m were laid inside landslides and adjacent to the landslide to compare tree density, vegetation cover and canopy cover of bamboo. |

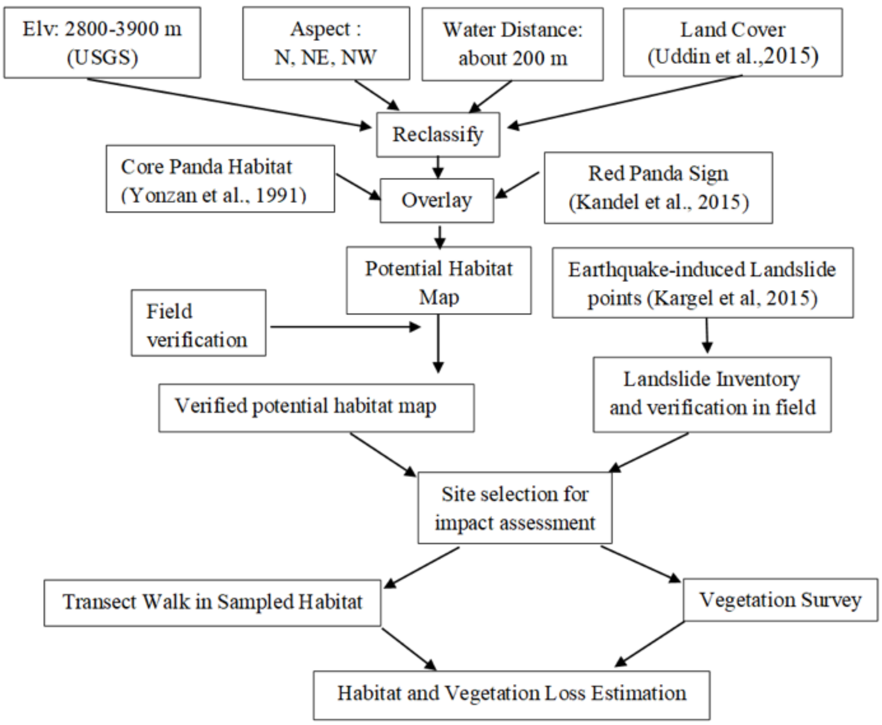


Figure 2. The methodological framework of the study.

Panda—the most reliable indirect evidence—was used for sign survey as the animals usually defecate at the feeding site and it is difficult to observe elusive Red Panda directly in the field (Wei et al. 1999c; Pradhan et al. 2001; Zhang et al. 2004; MoFSC 2016). Droppings of Red Panda and other mammals within 10 m of each transect were recorded. Only those damages such as landslides and habitats that occurred after the Gorkha earthquake were considered after confirming the locations with the help of the local guide and informants from the nearest settlements.

The vegetation (tree density and bamboo cover) within and adjacent to landslides were compared (Linderman et al. 2005). Shannon-Wiener index of diversity and Simpson Diversity index within each plot was also calculated. Shannon-Wiener index 'H' is commonly used to characterize species diversity in a community. It accounts for both the abundance and


Image 1. a—earthquake-induced landslide in the habitat of Red Panda: b—droppings observed around the landslide (within 10m).

evenness of the species present. It was calculated using the following formula (Shannon 1948).

$$H = -\sum_{i=1}^{S} \left(\frac{ni}{N}\right) \; ln\left(\frac{ni}{N}\right)$$

Where *S* is the number of different tree species, $n_i$ is the number of individual species, *N* is the total number of species.

Simpson Diversity index *D* is also a measure of diversity. It accounts for the number of species present, as well as the abundance of each species. It was calculated by the following formula (Simpson 1949).

$$D = \sum_{i=1}^{S} \left(\frac{n(n-1)}{N(N-1)}\right)$$

Where *S* is the number of different tree species, $n_i$ is the number of individual species, *N* is the total number of species.

The vegetation loss percentage within each landslide was also estimated. Data collected was analyzed using MS Excel 2013 and R (R Core Team 2020) to test significant differences in vegetation (i.e., tree density and bamboo cover) within and adjacent to earthquake-induced landslides. We used paired t-test to test the significant differences between the density and coverage of trees and bamboo in the sample sites within and adjacent to earthquake-induced landslides.

## RESULTS

### Potential habitat of Red Panda in LNP

This study estimated an area of 214.34 $km^2$ as the potential habitat of Red Panda in LNP. It is estimated that potential habitat including core habitat covers 12.53% of the total area of LNP. The presence points of Red Panda taken before the earthquake (red colour dots) falls within the estimated potential habitat (Figure 3). The recording of pellet groups (n= 27) and direct sightings of Red Panda (n= 3) in the potential habitat during the field visit indicate the validity of produced potential habitat map of Red Panda in LNP.

### Earthquake-induced landslides distribution

Earthquake-induced landslides in LNP were masked out from the earthquake-induced landslide distribution map produced by Kargel et al. (2015). Thirty-nine landslides were observed to occur in LNP as a result of the Gorkha earthquake (Figure 4). The earthquake-induced landslide distribution map produced shows that 14 landslides occurred only in the Multhala region (landslides detail in Table S1). These landslides were verified during the field visit. The minimum and maximum area of the landslides were measured to be 123 $m^2$ and 14,567 $m^2$, respectively. Most landslides occurred in the slopes of 45–55 on the north and north-east aspects which were distributed close to the water sources like rivers and streams. Most of the landslides (85.7%) were of dry and rockfall types.

The total area of the landslides within the potential habitat of Red Panda was estimated to be 111,975 $m^2$. This accounts for 2.6% of the sampled habitat. During the field study, it was observed that many landslides

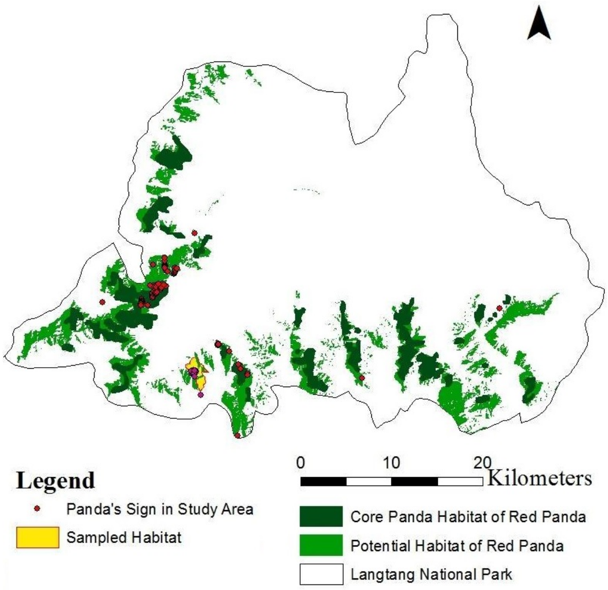


Figure 3. Potential and core habitats of Red Panda in LNP.

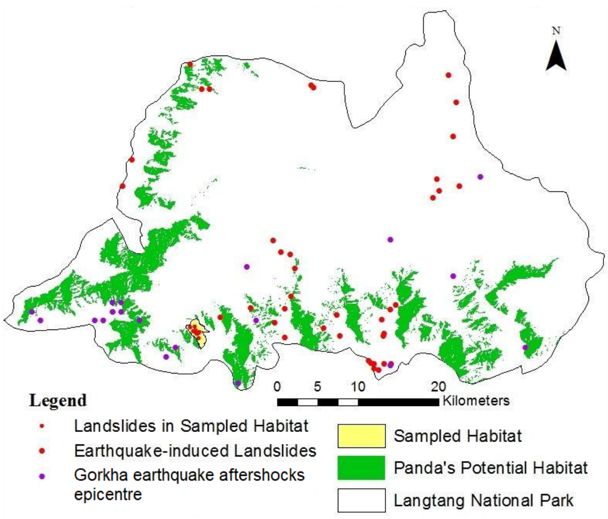


Figure 4. Earthquake-induced landslide distribution in LNP.

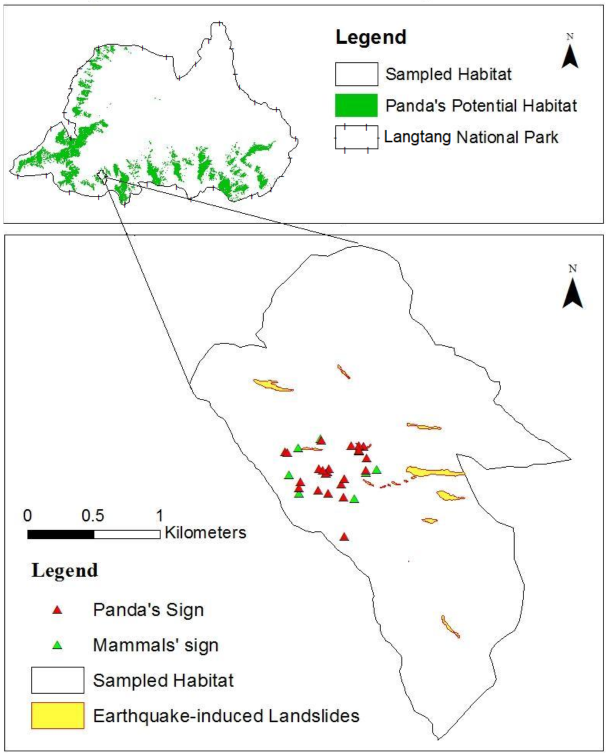


Figure 5. Landslides distribution in sampled habitat.

Table 2. Vegetation characteristics in the habitat affected by the landslide and adjacent habitat.

| Parameters | Habitat impacted by landslides | Habitat adjacent to the landslides |
|---|---|---|
| Shannon Diversity Index (H) | 0.99 | 1.017 |
| Simpson Diversity index (D) | 0.614 | 0.621 |
| Bamboo cover (%) | 0.147 | 0.521 |
| Tree density (no./$m^2$) | 2.714 | 2.828 |
| *Pinus wallichiana* (no./$m^2$) | 0.428 | 0.50 |
| *Rhododendron* sp. (no./$m^2$) | 0.87 | 0.90 |
| *Betula utilis* (no./$m^2$) | 1.30 | 1.414 |

were not included in the landslide distribution map produced by Kargel et al. (2015) as the work was solely based on remote sensing applications. It was also observed that some streams and springs had gone dry after the earthquake. The direct and indirect signs of Red Panda were recorded within sampled habitat (Figure 5). Indirect signs of other mammals were also observed within the sampled habitat (see Table S2).

## Impact on vegetation

Three species (*Pinus wallichiana, Rhododendron*, and *Betula utilis*) and bamboo cover were considered for vegetation analysis (Table S3 and S4). A significant decrease in trees density (80% less) was observed in the areas affected by the landslides. Similarly, the bamboo cover was observed to be significantly lower (71% less) in the areas affected by landslides compared to the adjacent area within the sampled habitat ($p < 0.05$). The mean value of both, bamboo cover and tree density, and diversity indices (Shannon & Simson) were found to be lower in the habitat affected by earthquake-induced landslides compared to the habitat without the impact (Table 2). However, diversity indices do not differ significantly between the two habitats.

### An estimated loss of Red Panda habitat

The presence of Red Panda in and around landslides was confirmed by fresh (n= 5) and old groups of pellets (n= 22) recorded during the transect walk (Image 2). The pallet groups were found in landslides (2 spots), within *Betula utilis* trees (9 spots), *Juniperous indica* tree/bush (4 spots), *Pinus wallichiana* tree (3 spots), Bamboo bush (3 spots), *Rhododendron* species (1 spot), on stone (3 spots), and bare land (2 spots). The average size of a landslide that caused damage to the Red Panda habitat in the sample site was calculated to be 7,998.21 m$^2$ (0.8 ha). The area of the potential habitat damaged by the earthquake-induced landslide was estimated to be 111,975 m$^2$ (11.2 ha). Based on the ecological density of Red Panda (one adult /2.9 km$^2$) (Yonzon & Hunter 1991b), the habitat loss was equivalent to the habitat of one adult Red Panda in LNP.

**Image 2. Red Panda *Ailurus fulgens* observed during the field expedition. © Saroj Shrestha, Red Panda Network**

## DISCUSSIONS

The potential distribution and quantified ecological niche of any species describe suitability and occurrence for supporting the survival of the species (Cushman & Huettmann 2010). The main factors that influence on habitat selection of Red Pandas are vegetation, source of water and human disturbance (Wei et al. 1998). Our study estimated the potential habitat to be 214.34 km$^2$ in LNP. The parameters used were: elevation range between 2,800 m and 3,900 m, distance from water sources up to 200 m, the land cover of broadleaf forest, evergreen forest, coniferous forest, shrubland, aspect of north, east, west, north-east, and north-west. The potential habitat map was in agreement with the distributions of Red Panda predicted by Kandel et al. (2015).

In the Hindu Kush Himalayan region, Thapa et al. (2018) estimated an area of 134,975 km$^2$ as potential habitat while Kandel et al. (2015) estimated potential Red Panda habitat at approximately 47,100 km$^2$ including 47.6% of potential habitat within Nepal and 27.8% within China. Compared to this, other studies have made 5.5–22.7% lesser estimates (Wei et al. 1999a,b, 2014; Choudhury 2001). Thapa et al. (2018), Kandel et al. (2015), and Mahato (2010) predicted an area of 20,150 km$^2$, 22,400 km$^2$, and 20,397 km$^2$, respectively, as the habitat of Red Panda in Nepal. A lower estimate of 8,200 km$^2$ has been made by Choudhury (2001). Two estimates have been made for LNP. Yonzon et al. (1991) considering suitable forest type, altitude, and aspect estimated an area of 68 km$^2$ as the suitable habitat, whereas Yonzon & Hunter (1991a) estimated an area of 108 km$^2$ as the suitable habitat of Red Panda. The distance from the water sources, one of the important parameters for habitat selection (Pradhan et al. 2001), was not incorporated in both studies. Furthermore, Pradhan et al. (2001) also recorded the occurrence of Red Panda in other forest types such as *Rhododendron, Betula utilis, Pinus wallichiana* forest besides *A. spectabilis* forest.

The number of earthquakes induced landslides in LNP was observed to be higher than estimated by Kargel et al. (2015). This could be due to the use of large sets of high-resolution satellite imageries for landslides mapping without intensive field visit as in the cases of other similar studies (e.g., Gorum et al. 2011). The sliding patterns were observed to be consistent in a diverse geological substrate and clustered near ridge crests, which are often the characteristics of earthquake-induced landslides (Meunier et al. 2008). The Red Panda habitat was damaged by the earthquake-induced landslides in LNP as the density of preferred vegetation varied significantly in the areas affected by the landslide. The earthquake-induced landslides also damaged the panda's preferred species for food. The tree density and bamboo cover were observed to be significantly lower in the areas affected by the landslides in comparison with the adjacent area within the sampled habitat. The preferred habitat of the Red

Panda is a forested area dominated by *Abies spectabilis, Rhododenron campanulatum, Betula utilis, Juniperus indica,* and *Arundinaria* sp., which provide ample food value and habitat for it (Pradhan et al. 2001; Sharma & Belant 2009). The spatial distribution of bamboo has a substantial effect on panda habitat (Linderman et al. 2005) as they are highly specialized to feed on bamboo (Kong et al. 2014). The loss in diversity and richness could be concerning as it may contribute to declines in forest productivity. Yet, disasters such as earthquakes may also contribute to new growth and higher forest diversity in the long term and large scale (Tilman 1996). The presence of remnant vegetation (20% on average) can be a driving factor for forest recovery. It is not only because it allows for seed dispersal, but also improves soil nutrient levels and raises soil humidity (Holl et al. 2000).

Although several studies have been conducted regarding the impact of the earthquake on wildlife habitats in other parts of the world, this is the first one in Nepal. This study estimated about 11.2 ha of the potential habitat of Red Panda in the LNP was affected by the earthquake-induced landslides that caused habitat degradation, fragmentation, and food loss. Furthermore, signs of other mammals observed in the damaged site indicate that the habitat of other wildlife were also affected by the landslides. The finding shows that the habitat required for only one panda has been affected in LNP. It is significant damage and threat to the elusive species considering its low population (24–68 individuals) in LNP and the practice of illegal hunting of this species in the area. Similarly, the fragmentation of habitat by the landslides could have severe consequences like damaging the food and associated trees favoured by Red Pandas. Mapping potential habitat for the Red Panda has broader implications in population estimates, forecasting, reintroduction, and science-based adaptive management in the LNP. Remote sensing and GIS application could be an essential tool to study the impact of the disaster on the wildlife habitat.

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**Table S1. Landslides in sampled habitat.**

| Landslide No | Lat. | Long. | Elevation (in m) | Slope | Aspect | Landslide type | Water status | Dead vegetation in landslide (in %) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 28.028 | 85.432 | 3,189 | 46–50 | N | rock fall | dry | 75 | |
| 2 | 28.028 | 85.432 | 3,236 | 45–55 | NE | rock fall | dry | 75 | old droppings |
| 3 | 28.0288 | 85.432 | 3,130 | 50–55 | NE | rock fall | dry | 75 | |
| 4 | 28.028 | 85.416 | 3,168 | 45–50 | N | rock fall | dry | 75 | |
| 5 | 28.026 | 85.417 | 3,201 | 45–55 | NE | rock fall | dry | 75 | |
| 6 | 28.028 | 85.429 | 3,343 | 45 | N | rock fall | dry | 75 | |
| 7 | 28.025 | 85.434 | 3,138 | 45–60 | NE | rock fall | dry | 90 | |
| 8 | 28.025 | 85.434 | 3,082 | 50 | NE | rock fall | dry | 90 | |
| 9 | 28.025 | 85.434 | 3,063 | 50 | SE | rock fall | dry | 90 | |
| 10 | 28.026 | 85.435 | 3,082 | 50 | SE | rock fall | dry | 75 | |
| 11 | 28.026 | 85.436 | 3,086 | 45 | NE | rock fall | dry | 95 | |
| 12 | 28.027 | 85.437 | 2,968 | 45 | NE | rock fall | Spring | 75 | mammal scat |
| 13 | 28.025 | 85.433 | 3,199 | 70–80 | SW | rock fall | Spring | 80 | |
| 14 | 28.020 | 85.436 | 3,190 | 45–50 | N | rock fall | dry | 75 | |

**Table S2. Sign of mammals (other than Red Panda) in the sampled habitat observed during field survey.**

| | Lat | Long | Elevation (m) | Animal sign (probably) |
|---|---|---|---|---|
| 1 | 28.026 | 85.434 | 3212 | Scat of unknown mammals |
| 2 | 28.028 | 85.430 | 3301 | Scat of deer (*Cervidae* sp.) |
| 3 | 28.028 | 85.428 | 3332 | Scat of deer (*Cervidae* sp.) |
| 4 | 28.026 | 85.428 | 3490 | Scat of goral (*Naemorhedus* sp.) |
| 5 | 28.025 | 85.428 | 3500 | Scat of yellow-throated martin (*Martes flavigula*) |
| 6 | 28.026 | 85.433 | 3232 | Fresh pellets of other mammals |
| 7 | 28.024 | 85.432 | 3390 | Scat of deer (probably *Cervidae* sp.) |

**Table S3. Vegetation data from quadrate sampling in the Red Panda habitat without landslide impact.**

| Quadrate | *Betula* sp. | *Rhododendron* sp. | *Pinus wallichiana* | Total number of trees | Bamboo cover % |
|---|---|---|---|---|---|
| Q1 | 5 | 4 | 0 | 9 | 80 |
| Q2 | 1 | 2 | 0 | 3 | 85 |
| Q3 | 1 | 0 | 0 | 1 | 25 |
| Q4 | 1 | 1 | 1 | 3 | 90 |
| Q5 | 0 | 1 | 4 | 5 | 80 |
| Q6 | 1 | 5 | 0 | 6 | 80 |
| Q7 | 3 | 1 | 0 | 4 | 75 |
| Q8 | 5 | 0 | 0 | 5 | 45 |
| Q9 | 0 | 1 | 0 | 1 | 25 |
| Q10 | 0 | 1 | 1 | 2 | 50 |
| Q11 | 0 | 1 | 1 | 2 | 40 |
| Q12 | 1 | 5 | 0 | 6 | 35 |
| Q13 | 5 | 0 | 0 | 5 | 20 |
| Q14 | 0 | 0 | 0 | 0 | 25 |
| Q15 | 0 | 0 | 1 | 1 | 5 |
| Q16 | 1 | 1 | 0 | 2 | 75 |
| Q17 | 0 | 1 | 1 | 2 | 80 |
| Q18 | 3 | 0 | 1 | 4 | 25 |
| Q19 | 2 | 0 | 1 | 3 | 20 |
| Q20 | 0 | 0 | 1 | 1 | 33 |
| Q21 | 0 | 2 | 0 | 2 | 35 |
| Q22 | 1 | 3 | 0 | 4 | 75 |
| Q23 | 3 | 0 | 0 | 3 | 20 |
| Q24 | 0 | 1 | 0 | 1 | 90 |
| Q25 | 0 | 1 | 0 | 1 | 80 |
| Q26 | 0 | 1 | 1 | 2 | 0 |
| Q27 | 0 | 1 | 0 | 1 | 5 |
| Q28 | 0 | 1 | 0 | 1 | 20 |
| Q29 | 2 | 1 | 0 | 3 | 10 |
| Q30 | 0 | 0 | 0 | 0 | 99 |
| Q31 | 1 | 1 | 0 | 2 | 75 |
| Q32 | 1 | 0 | 0 | 1 | 30 |
| Q33 | 0 | 1 | 0 | 1 | 75 |
| Q34 | 3 | 1 | 0 | 4 | 20 |
| Q35 | 0 | 0 | 0 | 0 | 45 |

| Quadrate | *Betula* sp. | *Rhododendron* sp. | *Pinus wallichiana* | Total number of trees | Bamboo cover % |
|---|---|---|---|---|---|
| Q36 | 0 | 1 | 0 | 1 | 55 |
| Q37 | 0 | 0 | 0 | 0 | 55 |
| Q38 | 1 | 1 | 0 | 2 | 75 |
| Q39 | 2 | 0 | 0 | 2 | 60 |
| Q40 | 1 | 0 | 0 | 1 | 80 |
| Q41 | 0 | 2 | 1 | 3 | 10 |
| Q42 | 0 | 1 | 0 | 1 | 85 |
| Q43 | 0 | 1 | 0 | 1 | 35 |
| Q44 | 1 | 0 | 0 | 1 | 95 |
| Q45 | 1 | 1 | 1 | 3 | 75 |
| Q46 | 0 | 1 | 4 | 5 | 70 |
| Q47 | 0 | 1 | 0 | 1 | 85 |
| Q48 | 0 | 0 | 5 | 5 | 65 |
| Q49 | 0 | 0 | 2 | 2 | 35 |
| Q50 | 0 | 1 | 3 | 4 | 75 |
| Q51 | 3 | 0 | 1 | 4 | 75 |
| Q52 | 7 | 0 | 0 | 7 | 20 |
| Q53 | 1 | 1 | 0 | 2 | 50 |
| Q54 | 0 | 1 | 0 | 1 | 95 |
| Q55 | 0 | 1 | 3 | 4 | 5 |
| Q56 | 3 | 3 | 0 | 6 | 25 |
| Q57 | 9 | 0 | 1 | 10 | 95 |
| Q58 | 3 | 3 | 0 | 6 | 5 |
| Q59 | 5 | 0 | 1 | 6 | 10 |
| Q60 | 3 | 1 | 0 | 5 | 0 |
| Q61 | 0 | 2 | 0 | 2 | 35 |
| Q62 | 0 | 3 | 0 | 3 | 61 |
| Q63 | 4 | 0 | 0 | 4 | 80 |
| Q64 | 4 | 0 | 0 | 4 | 95 |
| Q65 | 3 | 0 | 0 | 3 | 95 |
| Q66 | 3 | 0 | 0 | 3 | 25 |
| Q67 | 1 | 0 | 0 | 1 | 25 |
| Q68 | 1 | 0 | 0 | 1 | 75 |
| Q69 | 2 | 0 | 0 | 2 | 65 |
| Q70 | 1 | 0 | 0 | 1 | 85 |

**Table S4. Vegetation data from quadrat sampling in the Red Panda habitat with landslide impact.**

| Quadrate | *Betula utilis* | *Rhododendron* sp. | *Pinus wallichiana* | Total number of trees | Bamboo cover % |
|---|---|---|---|---|---|
| Q1 | 1 | 4 | 1 | 6 | 75 |
| Q2 | 1 | 4 | 1 | 6 | 25 |
| Q3 | 1 | 2 | 1 | 4 | 45 |
| Q4 | 4 | 1 | 2 | 7 | 55 |
| Q5 | 7 | 11 | 5 | 23 | 0 |
| Q6 | 0 | 0 | 5 | 5 | 90 |
| Q7 | 0 | 1 | 1 | 2 | 45 |
| Q8 | 0 | 1 | 1 | 2 | 80 |
| Q9 | 1 | 2 | 0 | 3 | 75 |
| Q10 | 0 | 1 | 0 | 1 | 66 |
| Q11 | 3 | 0 | 0 | 3 | 75 |
| Q12 | 0 | 4 | 2 | 6 | 25 |
| Q13 | 0 | 1 | 0 | 1 | 45 |
| Q14 | 1 | 1 | 0 | 2 | 10 |
| Q15 | 1 | 0 | 0 | 1 | 5 |
| Q16 | 2 | 0 | 0 | 2 | 5 |
| Q17 | 3 | 0 | 0 | 3 | 5 |
| Q18 | 0 | 1 | 0 | 1 | 1 |
| Q19 | 0 | 0 | 1 | 1 | 10 |
| Q20 | 0 | 0 | 0 | 0 | 10 |
| Q21 | 1 | 2 | 0 | 3 | 25 |
| Q22 | 1 | 3 | 0 | 4 | 10 |
| Q23 | 1 | 1 | 0 | 2 | 0 |
| Q24 | 2 | 0 | 0 | 2 | 10 |
| Q25 | 0 | 0 | 1 | 1 | 0 |
| Q26 | 0 | 0 | 0 | 0 | 10 |
| Q27 | 3 | 0 | 0 | 3 | 5 |
| Q28 | 0 | 1 | 1 | 2 | 30 |
| Q29 | 1 | 0 | 0 | 1 | 5 |
| Q30 | 0 | 1 | 0 | 1 | 2 |
| Q31 | 0 | 0 | 0 | 0 | 5 |
| Q32 | 1 | 1 | 0 | 2 | 5 |
| Q33 | 1 | 0 | 0 | 1 | 0 |
| Q34 | 2 | 0 | 0 | 2 | 0 |
| Q35 | 1 | 0 | 0 | 1 | 5 |
| Q36 | 1 | 0 | 0 | 1 | 2 |
| Q37 | 0 | 1 | 0 | 1 | 2 |
| Q38 | 1 | 1 | 0 | 2 | 0 |
| Q39 | 2 | 0 | 0 | 2 | 0 |
| Q40 | 1 | 0 | 0 | 1 | 2 |
| Q41 | 0 | 0 | 0 | 0 | 10 |
| Q42 | 1 | 1 | 0 | 2 | 20 |
| Q43 | 1 | 0 | 0 | 1 | 45 |
| Q44 | 0 | 1 | 0 | 1 | 10 |
| Q45 | 0 | 0 | 0 | 0 | 5 |
| Q46 | 0 | 1 | 0 | 1 | 5 |
| Q47 | 0 | 0 | 3 | 3 | 0 |
| Q48 | 0 | 1 | 1 | 2 | 5 |
| Q49 | 0 | 0 | 1 | 1 | 5 |
| Q50 | 0 | 0 | 1 | 1 | 5 |
| Q51 | 1 | 1 | 0 | 2 | 0 |
| Q52 | 1 | 0 | 1 | 2 | 0 |
| Q53 | 1 | 0 | 0 | 1 | 0 |
| Q54 | 1 | 0 | 0 | 1 | 0 |
| Q55 | 1 | 0 | 0 | 1 | 0 |
| Q56 | 11 | 3 | 0 | 14 | 0 |
| Q57 | 3 | 1 | 0 | 5 | 0 |
| Q58 | 7 | 1 | 0 | 8 | 5 |
| Q59 | 1 | 0 | 0 | 2 | 0 |
| Q60 | 3 | 0 | 0 | 3 | 0 |
| Q61 | 2 | 1 | 0 | 3 | 5 |
| Q62 | 3 | 0 | 0 | 3 | 15 |
| Q63 | 2 | 0 | 0 | 2 | 0 |
| Q64 | 1 | 0 | 1 | 2 | 2 |
| Q65 | 3 | 1 | 0 | 4 | 10 |
| Q66 | 3 | 1 | 0 | 4 | 5 |
| Q67 | 2 | 1 | 0 | 3 | 5 |
| Q68 | 3 | 0 | 0 | 3 | 0 |
| Q69 | 0 | 1 | 0 | 1 | 5 |
| Q70 | 2 | 1 | 0 | 3 | 5 |

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